New York State Water Resources Institute
Annual Technical Report
FY 2014

Introduction

The Mission of the New York State Water Resources Institute (WRI) is to improve the management of water resources in New York State and the nation. As a federally and state mandated institution located at Cornell University, WRI is uniquely situated to access scientific and technical resources that are relevant to New York State's and the nation's water management needs. WRI collaborates with regional, state, and national partners to increase awareness of emerging water resources issues and to develop and assess new water management technologies and policies. WRI connects the water research and water management communities. Collaboration with New York partners is undertaken in order to: 1) Build and maintain a broad, active network of water resources researchers and managers, 2) Bring together water researchers and water resources managers to address critical water resource problems, and 3) Identify, adopt, develop and make available resources to improve information transfer on water resources management and technologies to educators, managers, policy makers, and the public.

Research Program Introduction

The NYS WRI's FY2014 competitive grants research program was conducted in partnership with the NYS Department of Environmental Conservation (DEC) Hudson River Estuary Program (HREP). The overall objective of this program is to bring innovative science to watershed planning and management. In FY2014 research was sought that fit within the context of New York State’s concerns about aging public water resources infrastructure and related economic constraints on public investment. Additionally, competitive funding was directed toward projects that incorporated analysis of historic or future climate change and/or extreme weather and their impacts on communities, ecosystems, and infrastructure. The specific areas of interest for the FY2014 grants program solicitation were: 1) The current state and effectiveness of water-related infrastructure including water supply and wastewater treatment facilities; natural and “green” infrastructure; distribution networks; decentralized treatment installations; dams; culverts and bridges; constructed wetlands; etc., at providing water services regionally at reasonable cost, as well as how they compare to the natural systems they are replacing, augmenting or impacting; 2) Historic and/or future effects of climate change and extreme weather impacts on New York’s communities; and climate resilience of ecosystems, infrastructure, communities, and governance institutions and/or development of strategies to increase resiliency of these systems; 3) Integration of scientific, economic, planning/governmental and/or social expertise to build comprehensive strategies for local public asset and watershed managers and stakeholders; and 4) Novel outreach methods that enhance the communication and impact of science-based innovation to water resource managers, policy makers, and the public.

Projects were evaluated by a panel consisting of 3 WRI staff representatives, 1 Cornell University faculty member, 1 staff member from the NYS Department of Environmental Conservation, and 1 representative from the US Geological Survey (Ithaca office). Five research projects were initiated with 104b base funding, while another five were initiated and funded through DEC sources that WRI leverages with its base federal grant. For FY2014, 104b-funded projects include:

1. The Effect of Climate Change on the Unconfined Aquifers of Long Is land, New York
PI: Yuri Gorokhovich, City University of New York, Lehman College

2. Development of Regional Unit Hydrograph Parameters for Application to Ungaged NYS Watersheds
PI: James Kilduff, Rensselaer Polytechnic Institute

3. Integrating green infrastructure into the land use regulatory process through the City of Newburgh Conservation Advisory Council
PI: Jeffrey LeJava, Pace University

4. Pairing LIDAR, terrestrial laser scanning, and aerial photographs to make estimates of channel erosion due to large storm events
PI: Stephen Shaw, State University of New York College of Environmental Science and Forestry

5. Water Quality Assessment using Advanced Technology to Improve Adaptive Management of the St. Lawrence River
PI: Michael Twiss, Clarkson University

We also report on a 104g-funded project initiated in FY2012:

1. The remote monitoring of surface velocity, bathymetry, and discharge
PI: Edwin A Cowen, Cornell University

Additionally, WRI staff funded in part by the 104b program engaged in ad hoc research activities, the results of which are reported on below (authors in **bold** indicate WRI researchers):

1. **Rahm, B.G., and S.J. Riha**, 2014. Evolving shale gas management: water resource risks, impacts, and lessons learned. Environmental Science: Processes and Impacts 16:1400-1412. DOI: 10.1039/c4em00018h.

2. McPhillips, L.E., A.E. Creamer, **B.G. Rahm**, and M.T. Walter, 2014. Assessing drivers of dissolved methane patterns in central New York groundwater. J. Hydrol. Regional Studies 1:57-73.

The Remote Monitoring of Surface Velocity, Bathymetry, and Discharge

Basic Information

Title:	The Remote Monitoring of Surface Velocity, Bathymetry, and Discharge
Project Number:	2012NY189G
USGS Grant Number:	G12AP20155
Start Date:	9/1/2012
End Date:	8/21/2014
Funding Source:	104G
Congressional District:	22
Research Category:	Engineering
Focus Category:	Methods, Water Quantity, Hydrology
Descriptors:	None
Principal Investigators:	Edwin A. Cowen

Publications

1. Johnson, Erika D., E.A. Cowen, 2015, Remote Monitoring of Volumetric Discharge Employing Bathymetry Determined from Surface Turbulence Metrics, Water Resources Research, in review.
2. Johnson, E.D., 2015, The Remote Monitoring of Surface Velocity, Bathymetry and Discharge in Rivers and Open Channel Flows, PhD Dissertation, Department of Civil and Environmental Engineering, College of Engineering, Cornell University, Ithaca, NY.

Remote monitoring of volumetric discharge based on surface mean and turbulent metrics

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ABSTRACT: Traditional methods of directly measuring volumetric discharge are expensive, manpower intensive, and often require technicians to work in hazardous conditions. Here we have developed a reliable, continuous and efficient method of remotely monitoring volumetric flow rate. A series of Large-scale Particle Image Velocimetry (LSPIV) and Acoustic Doppler Velocimetry (ADV) measurements are made in a wide-open channel. The experiments are conducted for a wide range of aspect ratios, Reynolds numbers and Froude numbers. The results indicate that the mean surface velocity is related to the depth-averaged velocity and the surface integral length scale varies predictably with the flow depth, thus calculation of the flow rate is enabled. Our primary objective is to develop a non-contact discharge monitoring approach that will reduce stream-gaging costs at potentially better accuracy relative to current methods, while reducing hazards to USGS personnel.

1 INTRODUCTION

The United States Geological Survey (USGS) has been tasked with monitoring volumetric discharge (total volume of water flowing through a river cross section per unit time) in all of our nations' rivers and streams. Accurate determination of this fundamental hydrological parameter is essential in the design and operation of hydrologic engineering projects, the minimization of drought, the monitoring of water quality and the prediction of transport of environmental contaminants. Moreover, these data are used in the forecasting of public water supplies, in assessing environmental regulations and in flood control and damage mitigation. Simply put, accurate measurements of discharge are vital in the management of water as a national resource.

The current system used by the USGS to directly measure volumetric flow rate involves partitioning the river into a transverse series of finite segments and measuring vertical profiles of streamwise velocity in each segment. The volumetric discharge is then calculated using the velocity-area method formula,

$$Q = \sum\left(V_{avg} b H_{local}\right) \tag{1}$$

where Q represents the total volumetric discharge [m^3/s] and is equal to the summation of each segment's depth-averaged velocity, V_{avg} [m/s] times its width, b [m] and depth, H_{local} [m] (Rantz 1982). Traditionally, discharge measurements have been accomplished through traversing the river in a boat or through wading. Devices such as current meters or an Acoustic Doppler Current Profilers (ADCP) are typically used to measure the current velocity.

Because of the significant effort involved in measuring discharge, generally once a discharge measurement is made, it is related to the river stage (the elevation of the river surface above some arbitrary datum) occurring at the same time as the discharge measurement. Over time, the USGS has amassed a sizeable database of concurrent stage and discharge measurements for each of its ~ 7,300 gaging stations and has developed rating curves that express this functional relationship. The use of rating curves makes it possible for the USGS to continually estimate discharge by monitoring a river's stage, a measurement that is far easier to make on a continual basis.

Under ideal conditions, discharge determined from rating curves can be accurate to within 5% of the true value (Sauer & Meyer 1992). However, if the river is unstable or if the cross-section of the river varies widely an existing stage-discharge relation can become inaccurate. Flood conditions, releases from a dam, excess vegetation growth, a moving or soft erodible bed can all significantly influence a river's stage-discharge relationship. Figure 4 of Mason & Weiger (1995) provides such an example, where it can be observed that the discharge for a river stage of three feet changed by two orders of magnitude after a flood.

It is desirable to have accurate discharge data for all river flow conditions but the need is more urgent during floods. Discharge data is a key input into the river models developed by the National Weather Service (NWS), from which flood warnings and evacuation notices are made to the general public when dangerous conditions threaten. Without accurate discharge measurements it is difficult to predict precisely when a river will crest and when evacuations of local residents need to take place. Timely and accurate flood forecasts minimize economic damage and save human lives. A potential solution to this problem would be to make periodic measurements of discharge during floods. However, it is often the case that conditions are not safe and the risk to equipment and USGS personnel life are unacceptable.

Since direct measurements of discharge for all river conditions are time consuming and often hazardous to obtain, there have been many attempts at introducing remote sensing techniques to the process of stream gaging. Several attempts at incorporating radar technology have been made and were the primary focus of previous USGS task committees (e.g. Hydro 21). Several other investigations (Nicolas et al. 1997, Lee et al. 2002a, b, Mason et al. 2002, Costa et al. 2000, Melcher et al. 2002) have demonstrated the capacity of radar to make accurate velocity measurements of the water surface. However, in each of these studies the radar system used to measure the surface velocity could not simultaneously provide information about the bathymetry or the river depth. An additional measurement system that had to be, in all cases, traversed across the river was required to determine the river cross-sectional area and facilitate calculation of discharge.

Several investigations have focused on incorporating LSPIV and other optically based techniques into the process of stream gaging (Weitbrecht et al. 2002, Creutin et al. 2003, Creutin et al 2002, Fujita & Tsubaki 2002, Fujita et al. 1998). While LSPIV is capable of capturing instantaneous and accurate profiles of streamwise velocity across an entire field of view, here again, each of these studies relied on an additional measurement system to determine the river bathymetric information.

The technique that is proposed herein seeks to leverage the strengths of traditional PIV in the process of river gaging and further seeks to streamline the process by eliminating the need for a second measurement system to capture bathymetric information that is necessary to determine volumetric discharge. The required bathymetric information is extracted from the captured images through application of turbulence theory. Hence, the captured images of the water surface not only provide information about the mean surface flow but they simultaneously permit investigation of local bathymetric conditions. This is accomplished through the calculation of the integral length scale at the water surface, which we demonstrate to be correlated predictably to flow depth.

2 EXPERIMENTAL METHODOLOGY

2.1 *Wide-open Channel Flume*

A series of experiments were conducted in a recirculating, wide-open channel flume, described in detail in Liao & Cowen 2010, housed in the DeFrees Hydraulics Laboratory at Cornell University. The test section of the channel is 15 m long, 2 m wide and 0.64 m deep. The measurements conducted as part of this investigation were made ~9 m downstream from the inlet of the test section to allow sufficient distance for the boundary layer to fully develop. As illustrated in Figure 1, the origin of the coordinate system is located at the beginning of the test section, along the channel centerline, at the channel bed. The x coordinate indicates the streamwise direction, the y coordinate indicates the transverse and the z coordinate indicates the vertical direction.

2.2 *Experimental Cases*

Eight experimental cases were run, in which the flow depth was varied from 10.2 to 30.5 cm and flow speed was varied from 10.9 to 27.8 cm/s (Table 1). Of the dimensionless variables studied in these experiments and listed in Table 1, two that are of considerable interest here are the aspect ratio, B/H (where B is the channel width and H is the flow depth) and the ratio of boundary layer thickness to the flow depth, δ/H. The aspect ratio of the flow ranged from 6.6 – 19.7 across all the experiments. It has been noted by several investigators (Nezu et al. 1985, Albayrak & Lemmin 2011) and confirmed in this work that the aspect ratio sets the number of streamwise counter-rotating vortices in wide-open channels. The ratio of the boundary layer thickness

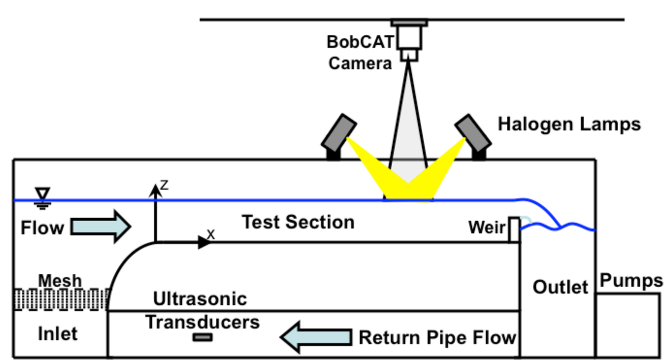


Figure 1. Schematic of the recirculating wide-open channel flume.

Table 1. Experimental Flow Cases

H [cm]	U_C [cm/s]	B/H	Re_H	Fr	δ/H	u*[cm/s]
10.7	11.3	18.7	10,680	0.10	2.03	0.50
10.2	24.6	19.7	25,400	0.25	1.87	1.17
15.2	11.0	13.1	15,210	0.08	1.42	0.51
15.3	27.8	13.1	38,275	0.20	1.24	1.12
20.6	11.0	9.7	20,550	0.07	1.05	0.49
20.3	27.5	9.9	50,725	0.18	0.94	1.12
30.5	10.9	6.6	30,460	0.06	0.71	0.48
30.5	25.0	6.6	76,175	0.14	0.62	1.10

U_C indicates the free surface centerline velocity. The Reynolds number, Re_H is based on the centerline velocity and flow depth. Fr is the Froude number. u* is the friction velocity.

to the flow depth, δ/H=0.62 – 2.03, is a critical parameter in these experiments that details what portion of the water column is comprised of the growing boundary layer. In other words, this parameter indicates how well developed the free surface flow is and how strongly it is influenced by the bed generated turbulence. In these experiments the boundary layer thickness, δ, has been estimated using Prandtl's 1/7th power law and the flow depth was set to achieve the desired range of δ/H values.

2.3 *Large-scale PIV Measurements*

Surface PIV experiments were conducted for each experimental case listed in Table 1 above. PIV is a well-established technique of fluid velocity measurement that is capable of characterizing an entire velocity field (Cowen & Monismith 1997). The technique employed here involves capturing images in rapid succession of the free surface of an open channel flow that has been artificially seeded with small buoyant particles. The average displacement of a small cloud of tracer particles is the same as the average displacement of that small region of surface fluid and when divided by the elapse time between images, yields an instantaneous surface velocity vector. The instantaneous velocity fields captured in successive images can be averaged in time to determine the mean velocity field. Subtracting the mean field from each instantaneous velocity field produces the instantaneous turbulent velocity field.

The experimental set-up for the LSPIV measurements includes a 12-bit IMPERX IGV-B2020 CCD camera that was suspended from the laboratory ceiling, approximately 3 m above the bed of the test section. This camera is capable of acquiring 123 fps and has a 2060 x 2056 pixel array. The camera was fitted with a 20 mm wide-angle lens with an aperture setting f/2.8. The field of view (FOV) of the camera is approximately 203 x 193 cm. The images cover the entire width of the channel in the spanwise direction (y = -100 to 100 cm) and x = 887 to 1091 cm in the streamwise direction. The spatial resolution in both directions was on average 0.105 cm/pixel. Great care was taken to ensure that the camera was mounted such that the imager plane was parallel to the flume bed.

The triggering of the camera and the timing of the image pairs was controlled through a computer running a MATLAB data acquisition code. The elapse time between two successive image pairs was varied according to the mean flow speed from Δt = 75 - 400 ms. A total of 4000 image pairs were captured at a sampling frequency of 1 Hz for each data set. The images were collected using the camera's software and saved on an external hard drive. A constant light source was provided through eight 500 W halogen lamps (four on the upstream side of the FOV and four on the downstream side).

The particles that are imaged in these experiments are Pliolite VTAC-L particles manufactured by OMNOVA. While these particles have a mean specific gravity of 1.03, there is a distribution of individual particle density, as evidence by their behaviour in water. The particles that float were preferentially selected for use in the experiments. The particles were sifted between a series of sieves and only particles in the range 420 - 600 microns (0.42 – 0.6 mm) were used in this study. The Stokes number for the particles is 0.003, indicating that the particles have ample time to adjust to the fluid flow.

All of the images were preprocessed prior to being analyzed. The stationary background of each image was removed applying the technique used by Mejia-Alvarez & Christensen (2013) and Honkanen & Nobach (2005). Following preprocessing, the images are processed via a FORTRAN algorithm that is an improved derivative of the algorithm described in Cowen & Monismith (1997).

2.4 *ADV Measurements*

Vertical profiles of velocity were made in the channel to characterize the properties of the flow throughout the water column using a Nortek Vectrino ADV. The ADV was moved vertically through the water column and measurements were taken at the approximate midpoint of the streamwise extent of the SPIV images (x = 981 cm). Five minutes of data were taken at each vertical position at a sample rate of 200 Hz. During post-processing the data was passed though a threshold filter and an adaptive Gaussian filter. The signal-to-noise ratio of these measurements was on average 16 dB and the correlation values were all high (> 93%).

2.5 *Ultrasonic Flowmeter*

An independent measure of volumetric flow rate was provided by a FLUXUS ADM 7407 ultrasonic flowmeter. Ultrasonic transducers were secured to both pipes that recirculate water to the test section and measurements were made for the duration of the

LSPIV tests. Volumetric flow rate was determined by summing the total amount of fluid flowing through both pipes. High quality flowmeter data (accuracy ± 3%) was ensured for all experiments and was judged through high values of signal quality (> 8) and signal-to-noise ratio (> 3) and accurate values of the sound speed of water in accordance with manufacturer specified recommendations.

3 RESULTS

Determination of volumetric flow rate using the velocity area method in Equation 1, requires knowledge of the depth-averaged velocity and the local flow depth across the entire width of the river. This section details how both the depth-averaged velocity and local flow depth can be determined solely from measurements of the surface velocity field. The section then concludes with a comparison of the volumetric flow rate calculated from the LSPIV imagery and from the ultrasonic flowmeter.

3.1 *Depth-averaged velocity*

Vertical profiles of streamwise velocity when normalized by the inner wall variables are observed to follow the logarithmic law with the von Kármán and the integral constants chosen consistent with the Nezu & Rodi (1986) and Nezu & Nakagawa (1993), $\kappa = 0.41$ and $B = 5.29$ (Figure 2). Because the ADV does not capture data in the viscous sublayer, the vertical profiles are extrapolated to the wall using the log-law. Prior measurements closer to the bed and not included here indicate that this is an appropriate course of action.

Depth-averaged velocity is determined simply by taking the weighted average of the streamwise velocity over the depth as indicated by Equation 2 below,

$$U_b = \frac{1}{H}\int_0^H U dh. \qquad (2)$$

Depth-averaged velocity is determined for each experimental case and compared with the mean surface

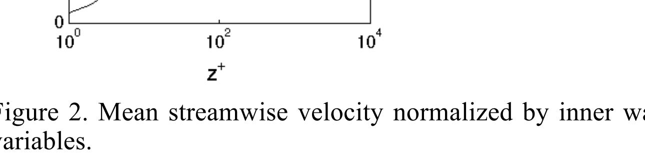


Figure 2. Mean streamwise velocity normalized by inner wall variables.

velocity measured by the LSPIV system in the same location that the ADV measurement was made. The ratio between these two velocities is found to vary with the ratio of boundary layer thickness to the flow depth, δ/H (Figure 3). As mentioned earlier, δ/H represents how well developed the free surface flow is. The range of values spanned in Figure 3, $U_b/U_{Surf} = 0.82 – 0.93$, is consistent with the range of values noted in other investigations. Harpold et al. (2006) measured a value of 0.95 in a laboratory channel. Rantz (1982) suggests that the ratio of depth-averaged velocity to surface velocity should fall between 0.84-0.92, with the lower values being more consistent with naturally occurring rivers and the higher values for laboratory flows. The range of values shown in Figure 3 plotted against δ/H corroborates the findings of Rantz (1982) and further reveal that lower values ($U_b/U_{Surf} \sim 0.85$) of this ratio correspond to free surface flows that are more fully developed such as the shallow flow cases in this study and naturally occurring rivers. With knowledge of this ratio one can predict depth-averaged velocities from corresponding measurements of surface velocities. For field applications of this methodology, given that a typical rivers' length much exceeds its depth, it is expected that the free surface will be quite well developed. The value 0.85, which is consistent with other studies, will be used.

3.2 *Local flow depth*

To determine local flow depth, we exploit the presence of streamwise counter-rotating vortices that occur in shallow open channel flows. These vortices have been well documented in several investigations (Shvidchenko & Pender 2001, Nezu 1993) and have been found to scale with the flow depth. Evidence that these structures exist in our channel can be seen in Figure 4. Instantaneous streamwise velocity fields as measured by our LSPIV system on the free surface for two flow cases (H=6.3 cm, U_c=26.2 cm/s H=20.3 cm, U_c=25 cm/s) are depicted in Figure 4. The horizontal striations that are present are alternating bands of high momentum (converging) and low momentum (diverging) fluid that are indicative of secondary flows influencing the free surface.

To quantify the size of these vortices, we calculate the integral length scale on the free surface. The integral length scale is the integral of the normalized autocorrelation function of the turbulent velocity fluctuations as seen in Equation 3. Because PIV yields a highly resolved spatial data set, a spatial correlation is performed as opposed to a temporal one. Both streamwise and transverse velocity fluctuations are considered, however because river bathymetry changes most rapidly in the lateral di-

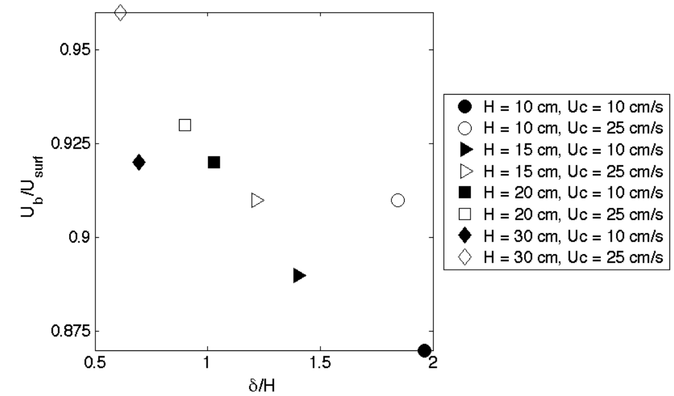
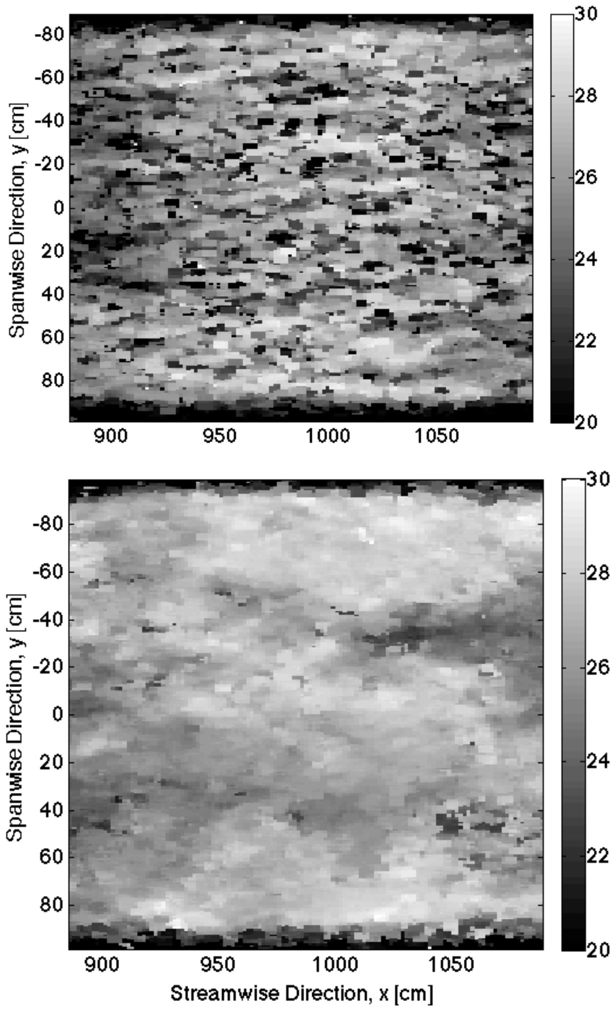


Figure 3. Depth-averaged velocity normalized by the mean surface velocity measured by the LSPIV system vs. boundary layer thickness normalized by the flow depth.



a.)

b.)

Figure 4. Instantaneous streamwise velocity. Contours are instantaneous streamwise velocity in cm/s. a.) Experimental case H=6.3 cm, U_C =26.2 cm/s. b.) Experimental case H=20.3 cm, U_C =25 cm/s.

rection, only correlations performed in the streamwise direction lead to unambiguous determination of flow depth.

In Equation 2 below, $a_{ij,k}$ is the normalized autocorrelation function and r is the separation vector. The subscripts *i, j,* and *k* are replaced with a 1 to indicate the streamwise direction and a 2 to indicate the transverse direction.

$$L_{ij,k} = \int a_{ij,k}(r)dr$$

$$\text{where, } a_{ij,k}(r) = \frac{\overline{u_i\left(x_c - \frac{1}{2}r_k\right)u_j\left(x_c + \frac{1}{2}r_k\right)}}{\left[\overline{u_i\left(x_c - \frac{1}{2}r_k\right)^2}\,\overline{u_j\left(x_c + \frac{1}{2}r_k\right)^2}\right]^{1/2}} \quad (3)$$

$L_{11,1}$ captures the streamwise distance over which the streamwise velocity fluctuations are correlated. It is calculated at every transverse location in the LSPIV field of view and depicted in Figure 5. With the exception of the 30 cm case, it is readily apparent that $L_{11,1}$ scales with the flow depth. The aberrant behavior of the 30 cm flow case is attributed to its low value of $\delta/H=0.62$, indicating a less developed free surface. Neglecting the influence of the corner vortices that occur near the sidewalls, the average across the central core of the flow is plotted in Figure 6. It is clear that $L_{11,1}$ is strongly correlated with the flow depth. For each flow case, $L_{11,1}$ is ~2.5 times the flow depth. The results further suggest a Reynolds number dependence.

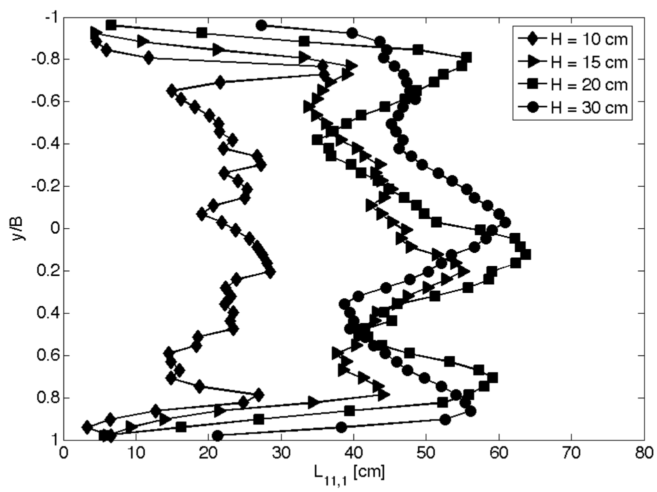


Figure 5. Streamwise integral length scale, $L_{11,1}$ vs. nondimensional channel width. The centerline velocity for all cases shown is ~25 cm/s.

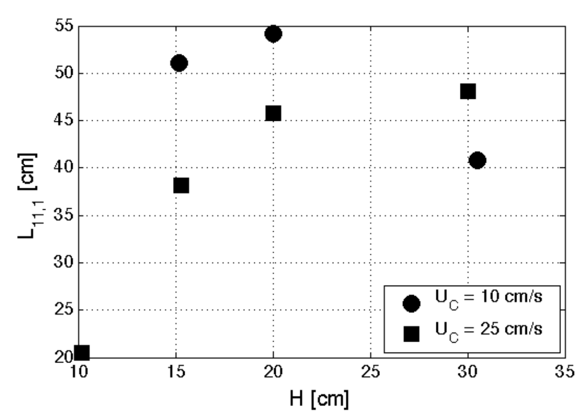


Figure 6. Mean streamwise integral length scale plotted against flow depth.

$L_{22,1}$ captures the streamwise distance over which the transverse velocity fluctuations are correlated. It is also calculated at every transverse location in the

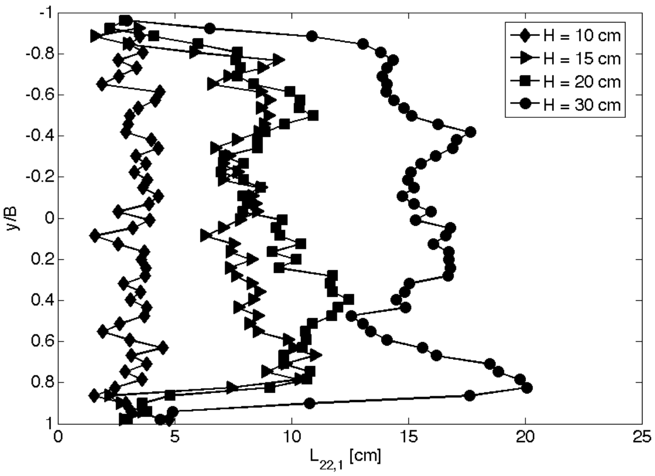


Figure 7. Transverse integral length scale, $L_{22,1}$ vs. non-dimensional channel width.

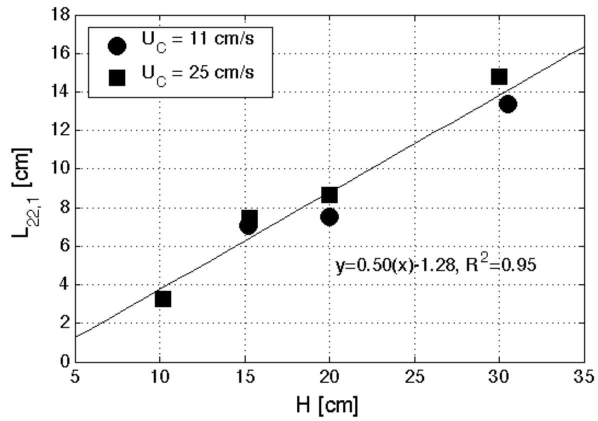


Figure 8. Mean transverse integral length scale plotted against flow depth.

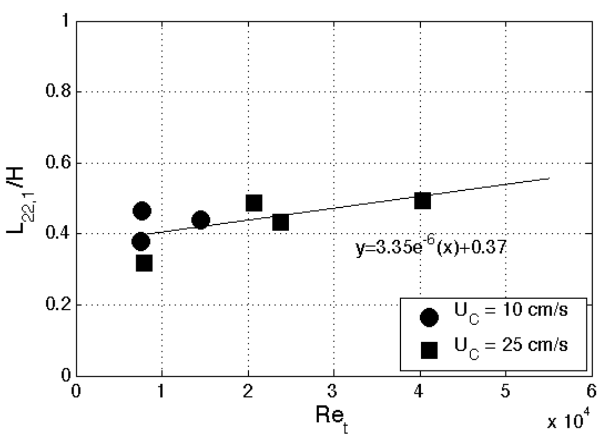


Figure 9. Turbulent Reynolds number versus normalized transvers integral length scale.

LSPIV field of view and depicted below in Figure 7 and Figure 8. $L_{22,1}$ is ~0.5 times the flow depth. The correlation between $L_{22,1}$ and the flow depth is even stronger.

Because free surface vortices will be larger in the field as compared with laboratory results, considering potential limitations of a camera's field of view $L_{22,1}$ is chosen over $L_{11,1}$, for estimating volumetric discharge. Our results are fully characterized when $L_{22,1}$ is normalized by the flow depth and plotted against the turbulent Reynolds number, Re_t, as in Figure 9. Because free surface vortices advect with the mean flow, the turbulent Reynolds number is formed with the mean local fluid velocity and $L_{22,1}$. As expected, $L_{22,1}/H$ shows a linear dependence on Re_t. It is trivial then to determine local flow depth using the relation given in Figure 9 and the known local values of surface velocity and integral length scale.

3.3 *Volumetric Discharge*

An estimate of the volumetric flow rate is thus enabled through knowledge of the relationship between the surface mean velocity and the depth-averaged velocity and the linear relation given in Figure 9. Predictions for volumetric discharge are compared with an independent measurement provided by the ultrasonic flowmeter and are shown in Table 2. The agreement between the measured and predicted flow rates is excellent.

Table 2. Measured and predicted volumetric discharge for experimental cases.

H [cm]	U_C [cm/s]	Q_{LSPIV} [m^3/hr]	$Q_{flowmeter}$ [m^3/hr]
10.2	24.6	150.93	143.85 ± 0.1
15.2	11.0	105.40	94.8 ± 0.2
20.6	11.0	137.08	138.14 ± 0.2
20.3	27.5	317.57	307.8 ± 0.3
30.5	10.9	214.16	204.54 ± 0.2
30.5	25.0	518.14	504.53 ± 0.4

Q_{LSPIV} designates discharge values calculated from LSPIV data. $Q_{flowmeter}$ designates discharge values measured with ultrasonic flowmeter.

4 CONCLUSIONS/FUTURE WORK

We have demonstrated that the surface velocity can be used as an accurate predictor of the local depth-averaged velocity. Our findings regarding this relationship are consistent with the work of many other researchers in both open channel and river flows. We have also demonstrated that the integral length scale, in particular $L_{22,1}$, is a reliable and powerful indicator of the local flow depth. Use of these two parameters has led to accurate predictions of volumetric flow rate.

Additional experiments have been completed to the effect that bed roughness will have on the free surface turbulent signatures and on the ratio of depth-averaged velocity to the mean surface velocity. Experiments in a channel with a trapezoidal cross-section and flood plain have also been conducted and are currently under analysis with the objective of studying how the surface integral length scale changes in regions of gradually changing local bathymetry. Validation of this methodology will also be carried out in two local rivers in conjunction with USGS personnel.

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Pairing LIDAR, terrestrial laser scanning, and aerial photographs to make estimates of channel erosion due to large storm events

Basic Information

Title:	Pairing LIDAR, terrestrial laser scanning, and aerial photographs to make estimates of channel erosion due to large storm events
Project Number:	2014NY208B
Start Date:	3/1/2014
End Date:	10/31/2015
Funding Source:	104B
Congressional District:	25
Research Category:	Climate and Hydrologic Processes
Focus Category:	Geomorphological Processes, Floods, Sediments
Descriptors:	None
Principal Investigators:	Stephen Shaw, Lindi Quackenbush

Publication

1. Halton, C. and S.B. Shaw, 2014. Evaluating short and long term changes in channel structure and associated sediment loads in McKinley Hollow, Catskill Mountains, NY, Catskill Environmental Research and Monitoring Conference, Belleayre Mountain, Highmount, N.Y. (poster)

Project Title: Assessing the Practicality of Terrestrial Laser Scanning to Observe Changes in Channel Morphology and Estimate Sediment Loads

Project Summary: In the academic literature, there is little documentation whether changes in natural stream channel structure occur due to relatively frequent large storm events (on the order of a 2-year return period) or from very rare cataclysmic events (100+ year return period). However, recent storm events on two water bodies in New York State in conjunction with new technology have provided an opportunity to directly assess the magnitude of channel forming flows.

Changes in channel structure have historically been analyzed by surveying cross-sections within a channel. This is a time-consuming approach and does not allow for the analysis of lengthy reaches in great detail. New technologies allow for more efficient and accurate three-dimensional analysis. Airborne Light Detection and Ranging (LiDAR) data collected by airplane fly overs within the past decade provide a baseline survey of three-dimensional channel structure at a large scale. But, due to the prohibitive costs of airborne LiDAR, it is rare to be able to collect this data frequently; often it is done only ever decade or so. However, while sacrificing spatial extent, terrestrial laser scanners can be used to collect ground-based LiDAR data at small spatial scales. Thus, terrestrial laser scanners can provide a means to make timely and relatively inexpensive detailed measurements of changes in channel morphology.

The basic objective of the study is to compare channel form before and after minor flow events (~ 2 year return period flow) and major flow events (> 25 year return period flow). Somewhat fortuitously, in the last several years – since airborne LiDAR was flown– there have been major flow events on Oneida Creek in Oneida County and Upper Esopus Creek in the Catskill Mountains. The Upper Esopus Creek watershed (McKinley Hollow site) in Ulster County, NY received approximately 10 inches of rain over a 24 hour period due to Hurricane Irene in August 2011, followed by approximately 7 inches due to Tropical Storm Lee only ten days later. The Oneida Creek watershed in Oneida County, NY experienced an approximately 25-year return period storm in June 2013. By comparing terrestrial laser scanner data collected in 2014 to aerial LiDAR (pre 2011), recent orthoimagery (pre and post 2011) , digitized historical aerial photography (pre 2011), and terrestrial laser scans in future years, we are in the process of documenting multi-decadal changes in channel structure in McKinley Hollow and Oneida Creek.

In addition, this study provides some insights into the practicality of using terrestrial laser scanners in place of airborne LiDAR to document changes in stream morphology at small scales.

Project Status: In summer 2014, four visits were made to the Oneida Creek site and two visits were made to the McKinley Hollow site (Figure 1). At each visit, approximately 200 m of stream channel were scanned with the terrestrial laser scanner. We are currently processing the scans made in 2014. This processing consists of: 1) “registering” the scans in Trimble RealWorks in order to stitch separate 20 m scans into full reach lengths (Figure 2), 2) identifying (Figure 3) and removing vegetation to show only bare earth points, and then 3.) converting the LiDAR point cloud into a digital elevation model (DEM) or other format more useful for processing in GIS or AutoCAD.

As noted above, these scans will be compared to historical airborne LiDAR as well as additional scans to be made in the summer of 2015. Comparison consists of visual assessment in changes in overall channel form as well as quantitative assessment of changes of sediment loss using “cut-and-fill” calculations within AutoCAD.

Presentations: Halton, C. and S.B. Shaw. 10/24/2014. Evaluating short and long term changes in channel structure and associated sediment loads in McKinley Hollow, Catskill Mountains, NY, Catskill Environmental Research and Monitoring Conference, Belleayre Mountain, Highmount, N.Y. (poster)

Student Support: A Master’s of Science graduate student was partially supported with these grant funds from Summer of 2014 to Spring of 2015.

Figure 1. Panoramic image of McKinley Hollow site in the Upper Esopus Creek watershed. The laser scanner is positioned on the tripod and the targets (round balls on poles) are visible on the left side of the image.

Figure 2. Registered point cloud created from data collected in McKinley Hollow on October 11, 2014. The color scale to the left of the image indicates elevation in meters.

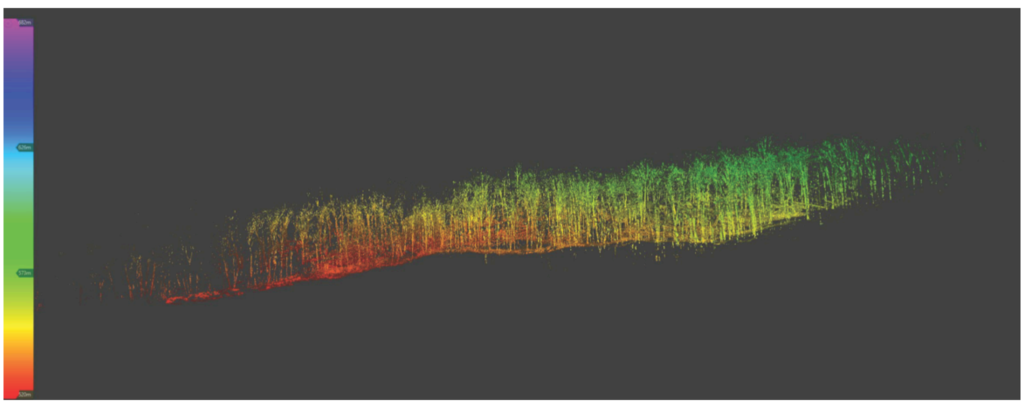
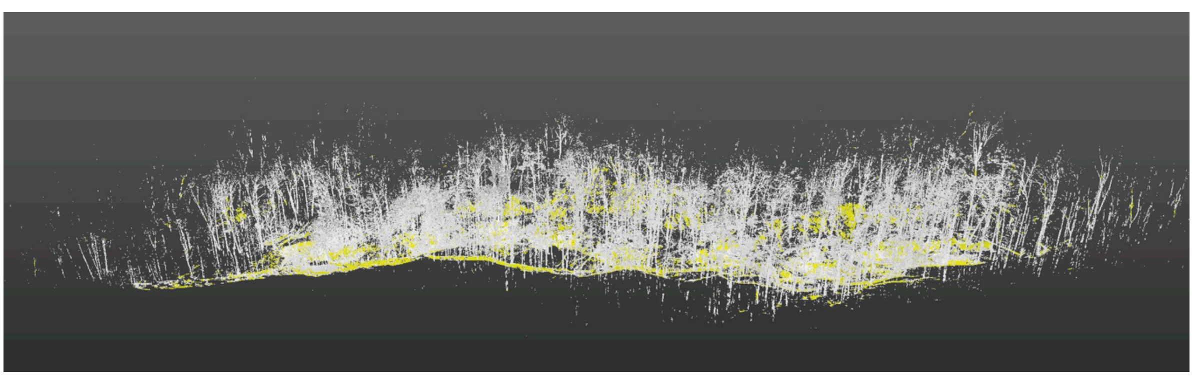


Figure 3. Point cloud shown in Figure 2 after separating bare earth points from vegetation.



The Effect of Climate Change on the Unconfined Aquifers of Long Island, New York

Basic Information

Title:	The Effect of Climate Change on the Unconfined Aquifers of Long Island, New York
Project Number:	2014NY209B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	13
Research Category:	Climate and Hydrologic Processes
Focus Category:	Groundwater, Water Supply, None
Descriptors:	None
Principal Investigators:	Yuri Gorokhovich

Publications

There are no publications.

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The Effect of Climate Change on the Unconfined Aquifers of Long Island, New York

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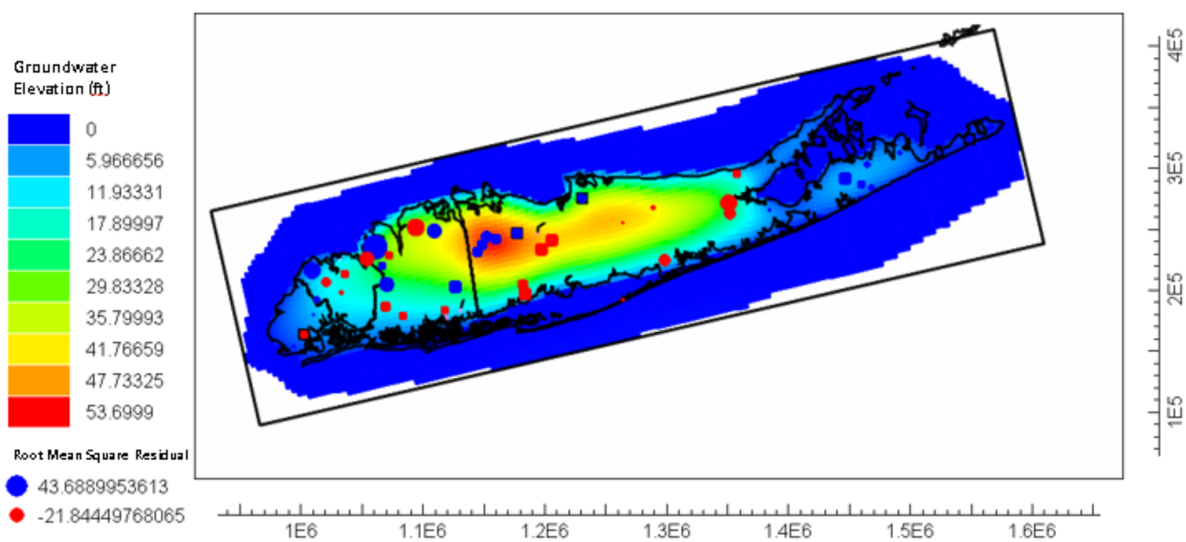

Abstract

Long Island sources all potable water from coastal aquifers confined by the Atlantic Ocean and Long Island Sound. Due to their limited recharge areas and disconnect with the mainland, these coastal aquifers are highly susceptible to the impacts of climate change through changing precipitation, evapotranspiration, and sea level rise. The potential for future reduction in groundwater capacity due to climate change and saltwater intrusion would impact the ability of the aquifers to support the water demands of growing populations, which would have social, political, and economic ramifications.

Summary Points of Interest:

- **Point 1 (Models are driven by data and calibration process; data compilation for calibration)**
- **Point 2 (Model includes three components: groundwater, climate change (specifically changes in precipitation) and salt water intrusion due to sea level rise.)**

Keywords: *groundwater, climate change, salt water intrusion, hydrogeologic modeling*

The Effect of Climate Change on the Unconfined Aquifers of Long Island, New York

Introduction

The impact of climate change on groundwater resources will play a large role in how regional communities will select adaptation measures and make future management decisions. The unconfined Long Island aquifers have the potential to be negatively impacted by climate change through reduced recharge and potential salinization due to the sea level rise. The results of this research will provide a baseline for establishing the magnitude of the effect of climate change on coastal aquifer storage capacity.

The overarching theme of the research project is the impact of climate change on recharge rates and saltwater intrusion on the Upper Glacial, Magothy, and Jameco aquifers (Figure 1) located on Long Island, New York, in Suffolk, Nassau, Kings, and Queens Counties. This study area offers scientific and future water management challenges due to its isolation from the mainland by the Long Island Sound, creating a naturally closed freshwater system. This isolation presents challenges for future groundwater management planning because no other water resources are available as alternative sources for Long Island. Therefore optimal management of the existing accessible supply is necessary. This research focuses on establishing a projection of future fresh groundwater availability for use by groundwater managers.

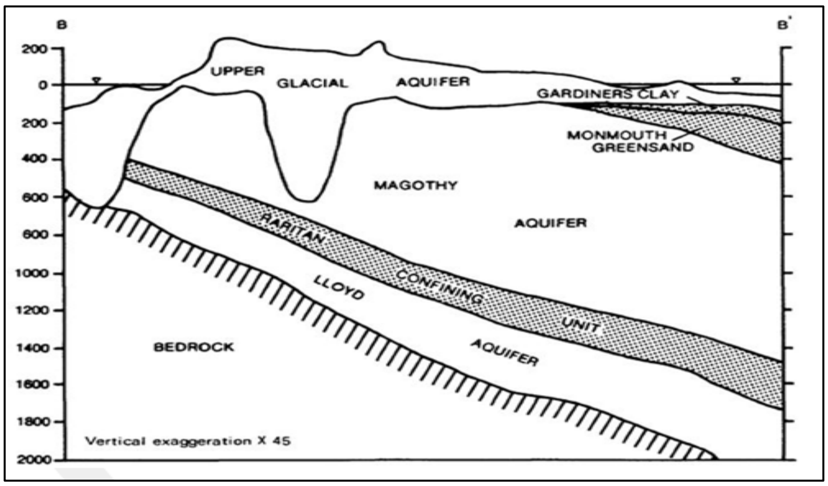

Figure 1. Major hydrogeolgic units of Long Island, New York (from Buxton, Smolensky, & Shernoff, 1989).

According to Neff et al. (2000) changes in global precipitation patterns due to climate change will impact the sustainable recharge of groundwater resources. Climate change also contributes to sea-level rise (SLR), which impacts rates of saltwater intrusion in coastal aquifers (Meehl et al., 2005; Titus et al., 1991). These factors affecting the hydrologic distribution of the unconfined aquifers on Long Island can be projected into the future using global circulation models (GCMs).

Between 1870 and 2004 there has been an observed global SLR of 195 mm (Church & White, 2006). Local projections of SLR in the North Atlantic Ocean may be as high as 230 mm by the end of the 21st century in the New York City metropolitan region, with estimated rates of previous SLR up to 2 mm per year (Yin, Griffies, & Stouffer, 2010). This may be compared to observations of the rate of SLR over the last century, ranging between 2.41 $\pm$0.15 through 2.27 $\pm$ 0.05 mm per year for the greater part of the 20th century in the New York City and Long Island, NY regions (Williams et al., 2009). Any increases in sea level will impact the Long Island aquifers by reducing the recharge area and volume of the aquifers. With less groundwater recharge and continuing SLR, saltwater is more likely to infiltrate the aquifers (Reilly & Goodman, 1985).

Misut & Voss (2007) performed a study focusing on western Long Island indicating that saltwater intrusion has been in decline since 1983, except in the confined Lloyd aquifer, which is experiencing a lag-time response to SLR during the Holocene. The decline in salinization coincides with the completion of the New York City (hereafter referred to as NYC) reservoir system in 1967, which transitioned all boroughs of NYC to surface water supplies and reduced groundwater extractions. Much of the groundwater salinization during the past century was related to the demand on groundwater supplies as a source of drinking water (Misut & Voss, 2007). Considering that NYC drinking water infrastructure is not expanding further westward into Long Island in the foreseeable future, and that some amount of climate change is inevitable (Wetherald, Stouffer, & Dixon, 2001; Wigley, 2005), the demands on the current fresh water supplies may increase. If pumping rates increase, the salinization rate of the aquifers may increase.
Climate change has far reaching implications. The future of our potable water resources is becoming more and more political, as privatization and overuse trends lead to increasingly difficult choices (Conca, 2008). Climate change and water resources will play a

large role on how society develops in the future, and this study seeks to clarify the overlap between the two areas. Climate research has recently been incorporated into hydrologic impact studies (Walker, 2013). The proposed study seeks to refine this process further, by investigating the uncertainty in the forecasting of the state of water resources and deliver more robust projections.

Methods

The first step is identifying and collecting spatial and temporal data on precipitation, discharge, temperature, barometric pressure, climatic projections, spatial dimensions of aquifers and related geologic units, topography, and the surface water network (streams and lakes) as input data to the model. The second step is to generate the computer model using the collected spatial and temporal data. These data will be modeled using the USGS groundwater model program MODFLOW-2005 (http://water.usgs.gov/ogw/modflow/) via USGS geographic user interface ModelMuse. Mr. Paul Misut, a USGS modeling specialist is working closely with the doctoral student throughout this process.

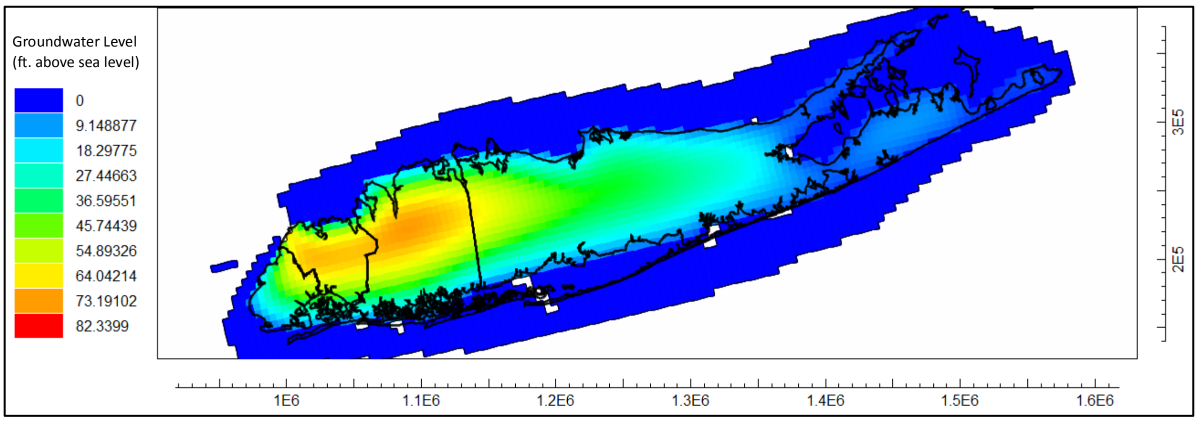

Figure 2. Preliminary modeling results: groundwater distribution on Long Island using MODFLOW. Early model iteration.

The process of generating basic groundwater computer model requires spatial and temporal adjustment and normalization of input data files to produce a realistic groundwater flow model in Long Island.

Upon completion of the parameterized computer model, the next step in the modeling process is calibration (Step 3). A subset from the historic hydrologic data from 1980-2010 will be used as calibration set to adjust modeling parameters, including both meteorological and climatic data as input (Step 4). After calibration we will conduct a verification process (Step 5) with another subset of data from 1980-2010 that should establish modeling uncertainty. The last step (Step 6) will consist of interpretation of modeling results.

This project is the core of a CUNY doctoral student's dissertation research, and is performed in partnership with the USGS (see letter of support). The funding from this grant opportunity will be used for the creation and calibration of the groundwater model. Preliminary modeling work and training during the summer of 2013 at Colorado School of Mines (a course on Groundwater Modeling) has been undertaken by the doctoral student in order to master the basic computer modeling skills.

Results & Discussion

This work has resulted in a more robust and calibrated model. The model calibration has improved greatly from the first iteration. Initial work included matching the working model with the old USGS HA-709 model (Smolensky et al. 1990). That model stands as an outdated industry standard, so our aim was to mimic their physical model, though on a smaller scale and incorporating some newer information since HA-709 was generated and utilized in 1990. Figure 3 shows the USGS transects and the model transects used for the calibration process.

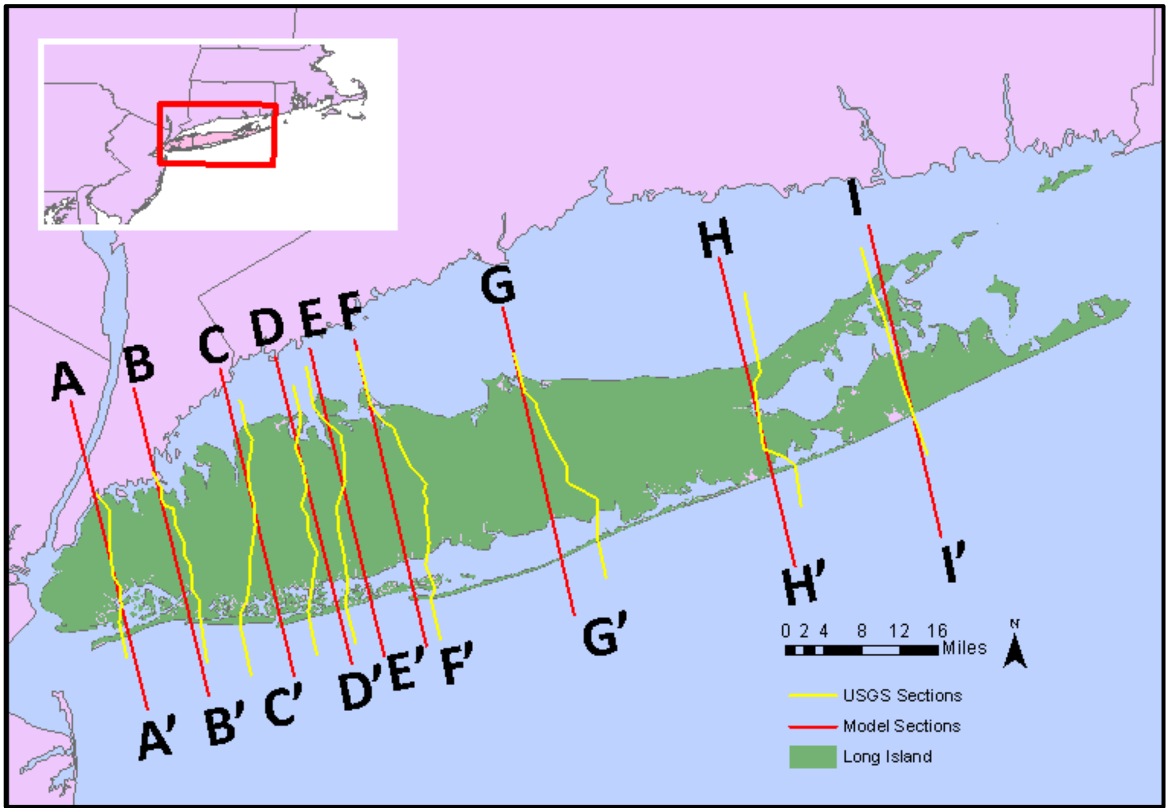

Figure 3. Transects and cross sections used in model comparisons.

The goal was to ensure that our model's cross sections were similar to those of the USGS in order to identify areas of similar geology. Once the geology was set up, the different areas of recharge, precipitation, hydraulic conductivity, stream drains, etc. could be added to the model. Figures 4 through 8 show these comparisons.

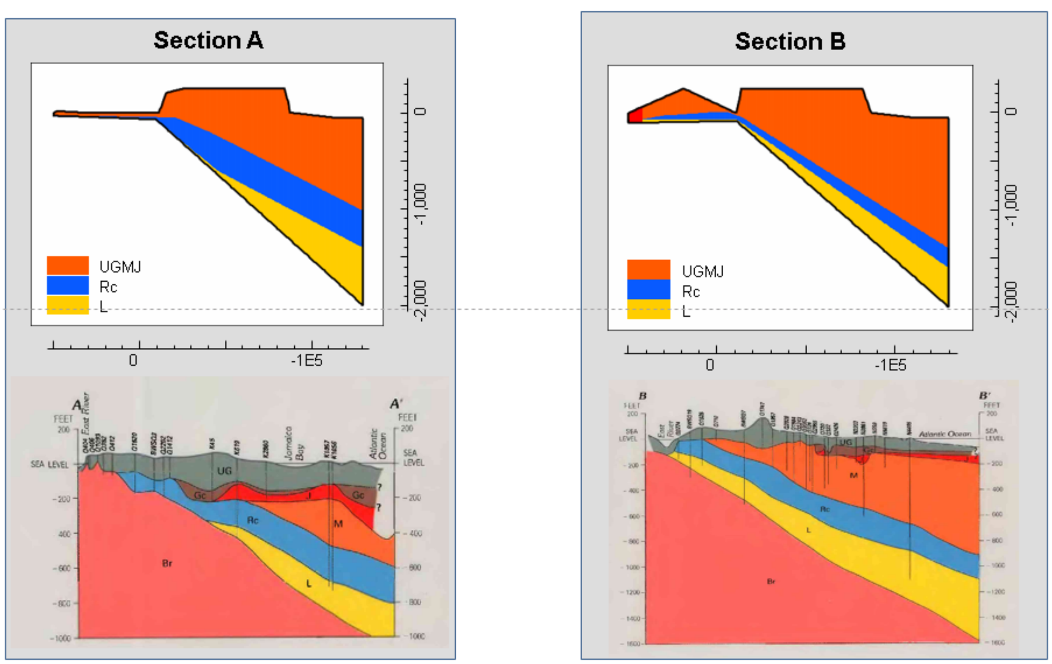

Figure 4. Model calibration comparisons for section A and B. ModelMuse in upper half, USGS HA-709 in lower half.

This report was prepared for the New York State Water Resources Institute (WRI) and the Hudson River Estuary program of the New York State Department of Environmental Conservation, with support from the NYS Environmental Protection Fund.

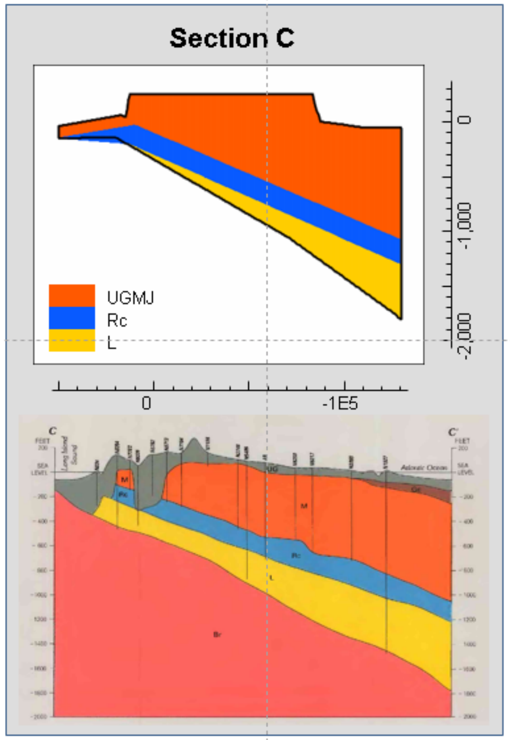

Figure 5. Model calibration comparisons for section C. ModelMuse in upper half, USGS HA-709 in lower half.

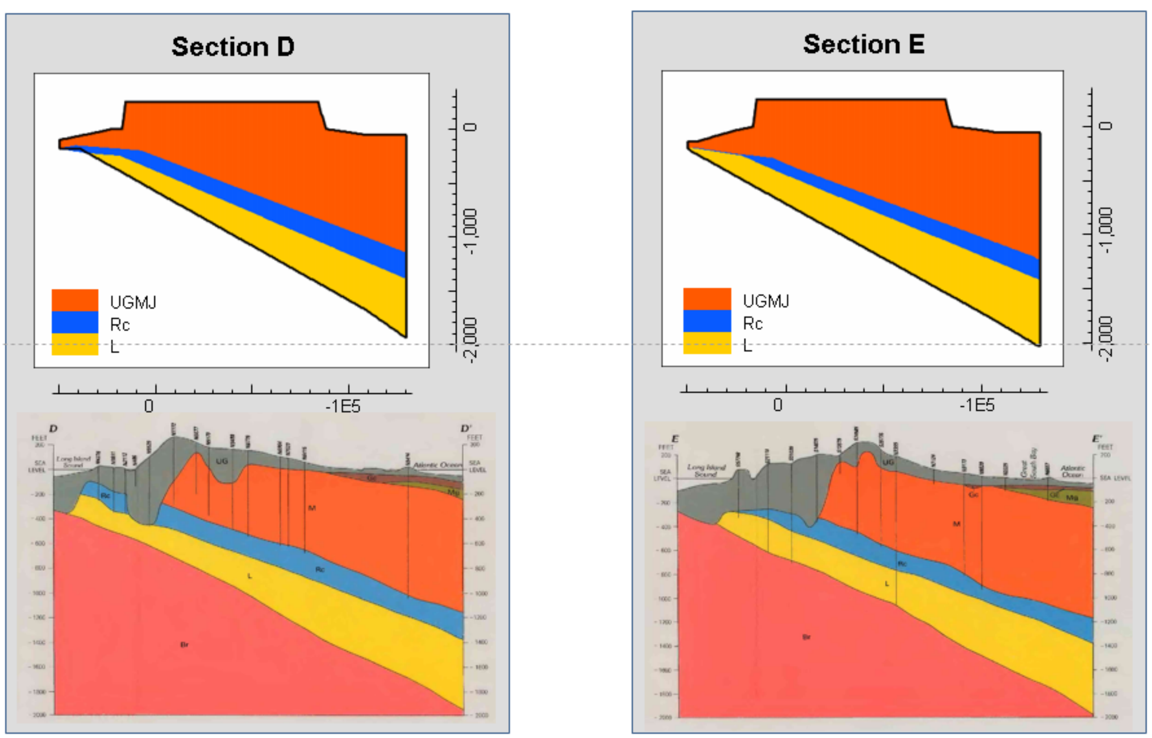

Figure 6. Model calibration comparisons for section D and E. ModelMuse in upper half, USGS HA-709 in lower half.

This report was prepared for the New York State Water Resources Institute (WRI) and the Hudson River Estuary program of the New York State Department of Environmental Conservation, with support from the NYS Environmental Protection Fund.

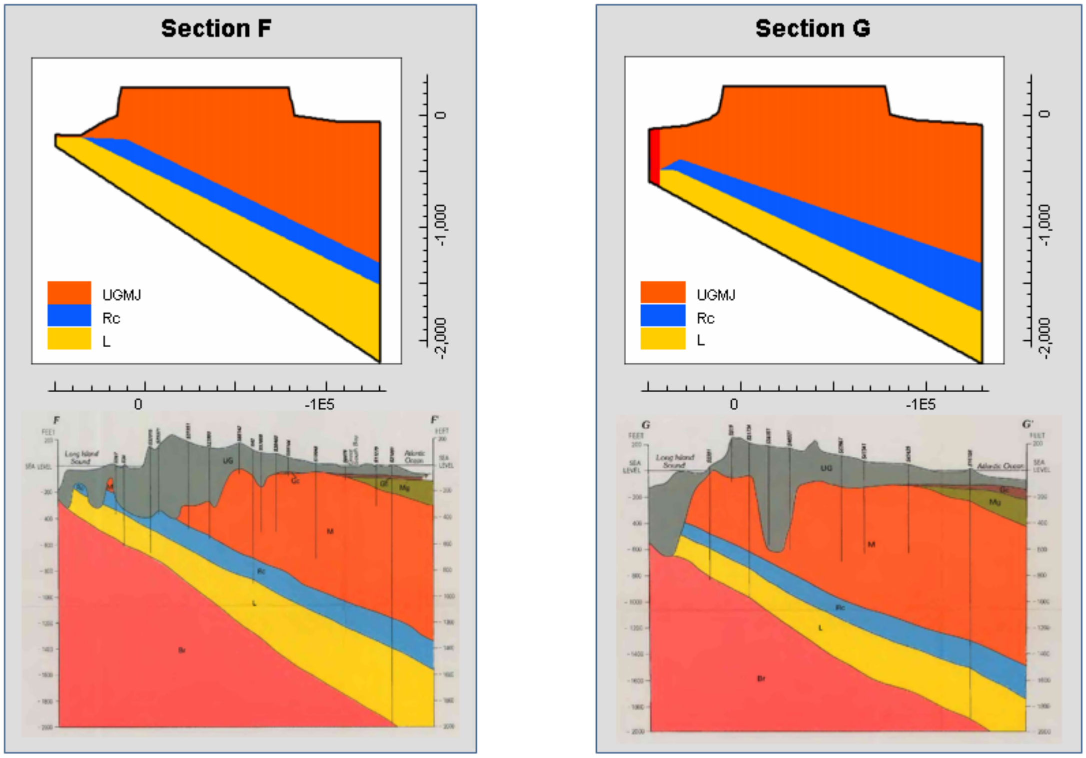

Figure 7. Model calibration comparisons for section F and G. ModelMuse in upper half, USGS HA-709 in lower half.

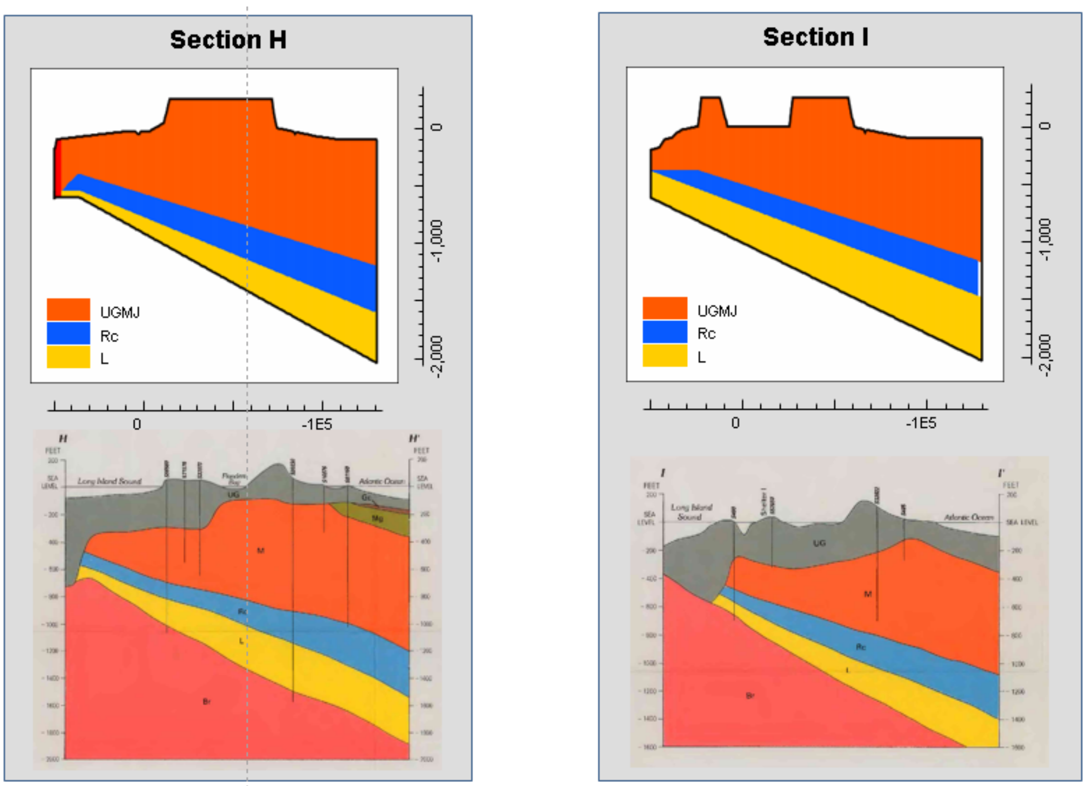

Figure 8. Model calibration comparisons for section H and I. ModelMuse in upper half, USGS HA-709 in lower half.

This report was prepared for the New York State Water Resources Institute (WRI) and the Hudson River Estuary program of the New York State Department of Environmental Conservation, with support from the NYS Environmental Protection Fund.

Upon completing the physical model, we needed to continue to refine the variables to provide a realistic groundwater elevation. Figure 9 shows the current working model, with residuals. The residuals represent calibration points and differences between simulated and actual values. The root mean square residual value has been reduced from 74 to 11 during the calibration process, indicating the improved accuracy of the model. Figure 10 shows the calibration points in relation to the line y=x.

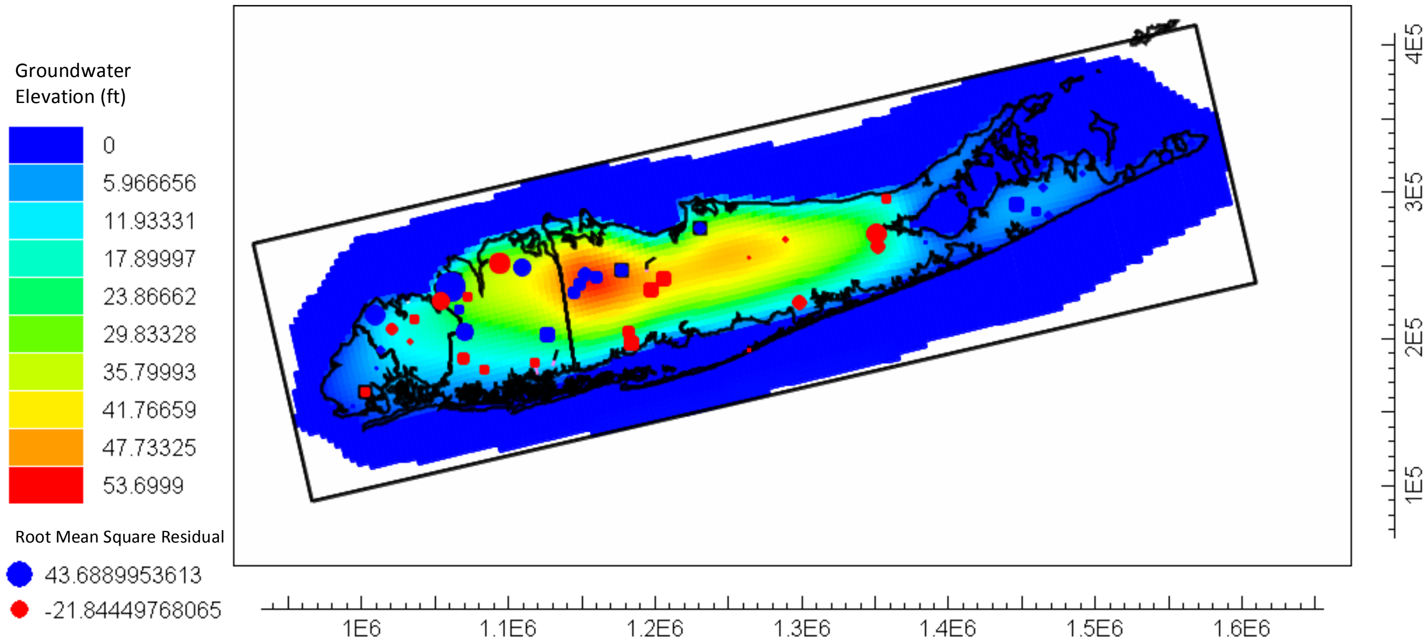

Figure 9. Current model iteration with calibration residuals.

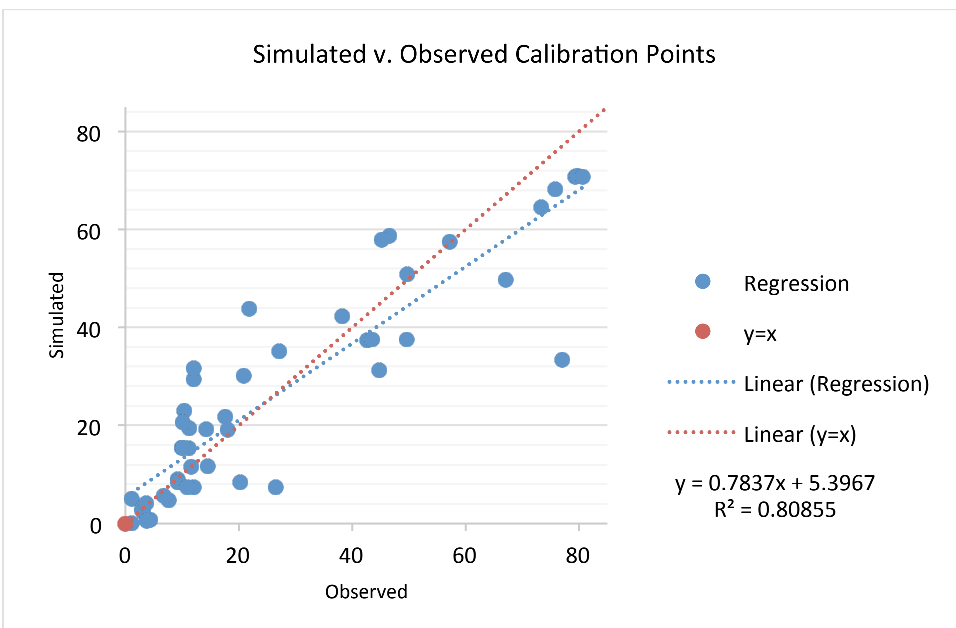

Figure 10. Calibration pointes for model in Figure 9.

This report was prepared for the New York State Water Resources Institute (WRI) and the Hudson River Estuary program of the New York State Department of Environmental Conservation, with support from the NYS Environmental Protection Fund.

The Effect of Climate Change on the Unconfined Aquifers of Long Island, New York

Policy Implications

This research will result in a working groundwater model of Long Island that will be used to simulate the impact of climate change on groundwater capacity of the coastal aquifers. The future of our potable water resources is becoming more and more political, as privatization, absence of conservation measures and overuse add stress to existing water management strategies and policies. Currently, the two Long Island counties of Nassau and Suffolk have over 500 public water systems that rely on more than 1,500 different groundwater wells for their supply. Due to the absence of water conservation measures and development in general, the recharge areas for these aquifers is decreasing and thereby reducing the available groundwater supply. Continued sea-level rise, together with increasing water usage and the decreasing recharge areas, will cause more salt water intrusion into the Long Island aquifers. In the 19th century this phenomenon caused New Yorkers to draw upon the surface water supply from the nearby Croton Reservoir. A similar scenario might happen to Long Island residents as degradation of water quality by intrusion of chloride, nitrates, and sulfates continues into the 21st century, as anticipated.

Student Training

At the present time the goal is for one doctoral level student to be fully trained as a groundwater modeler, which involves both the creation of the model from scratch by the doctoral student, as well as the calibration of the model. Both of these processes are time consuming and complex skills that may be passed on eventually as relevant teaching opportunities by the doctoral student upon completing her research. The graduate student worked in conjunction with a USGS mentor to improve her modeling skills throughout this process. She learned how to improve her precision and accuracy in the modeling process. In addition, she learned how to locate and incorporate outside data sources into the modeling process, improving the accuracy of the model. The student is currently nearing the end of the calibration process, having learned the skills necessary to navigate ModelMuse, ModelMate, and MODFLOW.

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This report was prepared for the New York State Water Resources Institute (WRI) and the Hudson River Estuary program of the New York State Department of Environmental Conservation, with support from the NYS Environmental Protection Fund.

Water Quality Assessment using Advanced Technology to Improve Adaptive Management of the St. Lawrence River

Basic Information

Title:	Water Quality Assessment using Advanced Technology to Improve Adaptive Management of the St. Lawrence River
Project Number:	2014NY210B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	21
Research Category:	Water Quality
Focus Category:	Water Quality, Law, Institutions, and Policy, None
Descriptors:	None
Principal Investigators:	Michael Twiss, Joseph Skufca

Publications

1. Neff, F.C., H.M. Sprague, J.D. Skufca, and M.R. Twiss, 2014, Water Quality Monitoring of the Upper St Lawrence River Using Remote Sensor Arrays Placed in a Hydropower Dam Combined With Hydrodynamic Modeling, American Geophysical Union Fall Meeting, American Geophysical Union, San Francisco, CA, (poster).
2. Russo, A.D., F.C. Neff, H.M. Sprague, S.E. Loftus, J.D. Skufca, and M.R. Twiss, 2015, Water Quality Monitoring of the Upper St Lawrence River Using Remote Sensor Arrays Placed in a Hydropower Dam Combined With Hydrodynamic Modeling, International Association for Great Lakes Research Annual Meeting, International Association for Great Lakes Research, Burlington, VT, (poster).

Final Report to the New York State Water Resources Institute

Water Quality Assessment using Advanced Technology to Improve Adaptive Management of the St. Lawrence River

Project period: March 1, 2014 - February 28, 2015.

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Project abstract: The project incorporates the development and deployment of a novel and innovative cost-effective observing technology approach that can meet identified data gaps to support the high priority focus area of enhanced ecosystem integrity through improved resource management, as identified in the New York State Great Lakes Action Agenda. A sensor station located in a hydropower dam was established on June 17, 2014 that continuously detects and records nearshore water quality in the St. Lawrence River. Observations of continuous water quality measurements allow tracking and forecasting of climatic, biological and changes in the Great Lakes ecosystem in relation to changes in river hydrology. The project supports data-driven decisions regarding adaptive management and the cost-effective planning of coordinated surveillance and monitoring of these resources and is part of a burgeoning smart infrastructure being developed in the Great Lakes basin to address water resource management.

Project Overview

Statement of project focus: In a rapidly changing world, water resources in the Great Lakes-St. Lawrence system are threatened as ecosystem integrity is challenged. Accordingly, we need to respond rapidly to threats and thus, appropriate tools and approaches are required. According to Annex 10 of the 2012 Great Lake Water Quality Agreement (GLWQA) adaptive management is to be used as a "*framework for organizing science to provide and monitor the effect of science-based management options*". We are working to develop the condition wherein science-based management of connecting channels (i.e. large rivers, such as the Saint Lawrence) is assisted by a data-rich information base provided by riverine sensor arrays. The project incorporates the development and deployment of a novel and innovative cost-effective observing technology approach.

Article 1.c of the revised GLWQA explicitly states that the major rivers (Figure 1), which comprise the natural outflows amongst the Great Lakes, are integral components of the Great Lakes ecosystem and thus, these rivers are now required to be monitored and assessed according to the GLWQA (Annex 2). This is a marked change from the earlier GLWQAs and puts added stresses on increasingly limited budgets and personnel that are now required to add additional resources to meet the new requirements. For the Lake Ontario Lakewide Action and Management (LAMP) this is a particularly acute case. The LAMP must now not only incorporate the Niagara River but also the St. Lawrence River, which alone has a shoreline that *exceeds* that of Lake Ontario. A recent (March 2015) survey of operators of advanced water quality sensors in the Great Lakes-St. Lawrence River (GL-SLR) region shows (Figure 1) that the St. Lawrence River has very few operators capable of supporting new LAMP needs.

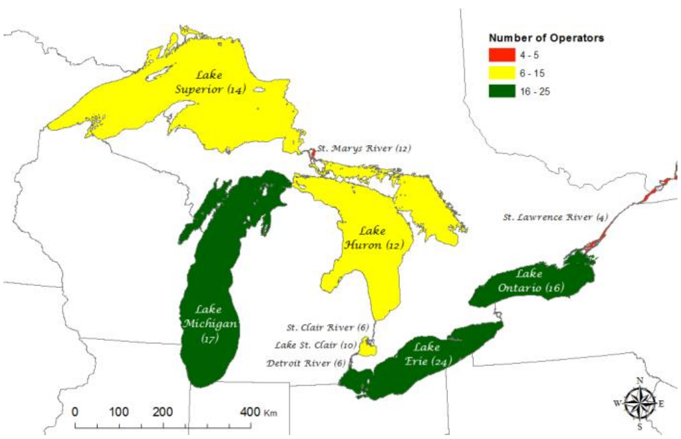


Figure 1. *Number of water quality sensing operations in the Great Lakes region showing that the St. Lawrence is underrepresented despite its size and the need to support adaptive management of this resource. <u>Source</u>: Twiss & Stryszowska; unpublished report for the Science Advisory Board of the International Joint Commission.*

The objective of this project is to continuously detect and record nearshore channel water quality in the St. Lawrence River by operating a sensor station in a hydropower dam. In combination with observed water quality measured upstream and hydrodynamic modeling we will determine the extent of upstream river that can be detected with a known level of confidence from the dam location that allows for satisfactory prediction of upstream water quality throughout all times of the year. The importance of this work lies in the valuable environmental data that will be collected *year-round* that can be used to discern impacts of controlled and uncontrollable stressors on water quality in this ecosystem. Location of the sensor array in the power dam will allow for changes in water quality to be detected at high resolutions and related to environmental changes being experienced at a broader scale. Full realization of the project outputs will provide water resource managers with the desired ability to more efficiently assess point source compliance with discharge parameters, understand non-point source watershed run off and tributary loading, assess chronic and episodic events such as releases from vessels or combined sewer overflow, as well as identify the impacts of extreme weather events on water quality.

Scope of Work: The goals of this project are to:

I. Maintain year-long continuous high-resolution monitoring of nearshore water quality in the St. Lawrence River through sensor array set up in the Moses-Saunders power dam.
II. Establish the hind-casting capabilities of the hydropower dam sensor arrays.

Large systems such as the Saint Lawrence River require sensors to be placed in reasonable locations. Installing sensor arrays in hydropower dams offers 365 day per year coverage. In comparison, sensors on buoys are limited to ice-free conditions (April to December), suffer from more environmental stresses and potential catastrophic losses (e.g., buoy mooring failure, collisions), damage during deployment and recovery, less opportunity to clean and maintain sensors, and are more expensive and hazardous to deploy and maintain. Sensor arrays installed *in* hydropower dams is an innovative approach to water quality monitoring that has yet to be capitalized.

Location of Continuous Water Quality Monitoring Stations inside a Hydropower Dam: Permission from the New York Power Authority (NYPA) allowed us to install a sensor array at the Moses-Saunders hydropower dam (Upper St. Lawrence River; USLR) using water that flows continuously through the No. 32 generating unit located closest to the US shore. The sensor station in Unit 32 is justified as follows:

i) The St. Lawrence is the only natural outflow of the entire Great Lakes. The dam has an impact on the regional ecology of the river. The US side of the dam is entirely within a USEPA Area of Concern.
ii) Water in the main channel of the river strongly reflects water quality of the head water lake, Lake Ontario. However, since the hydraulic residence time of the USLR is 12 days, it follows that there is appreciable retention of water in slower moving water masses that are characteristic of nearshore zones (Fig. 2). Nearshore locations provide a measure of main channel water mixed with nearshore waters impacted by point sources (e.g., CSO) as well as diffuse sources (e.g., land runoff).
iii) Transects along the nearshore and in the main channel from the Moses-Saunders dam to 40 km upstream indicate that tributary and slack water impacts on river water quality are detectable.
iv) Eel ladders located on units nearest each shore allows continuous water quality monitoring to be related to fish migration behavior.

v) The arrays will not freeze during winter operations since they are located within the dam, unlike sensor arrays deployed on buoys that must be removed during winter. We have demonstrated no effect of temperature in the Moses-Saunders dam on measured water temperature due to high rate of flow through sensor array and insulation of pipes.
vi) The hydropower dam has secure access that provides for well-protected instrument arrays, safe access for personnel, and year-round observations.

Sensor Description and Installation — The following time-stamped water quality parameters are measured at high frequency (0.1 Hz; 1/min): (*i*) water temperature, (*ii*) specific conductivity, (*iii*) turbidity, (*iv*) colored dissolved organic matter (CDOM), (*v*) in vivo chlorophyll-*a* (Chl-*a*), and (*vi*) in vivo phycocyanin (an indicator of potentially toxigenic cyanobacteria). These parameters are measured using two calibrated submersible instruments, a sonde (YSI model 6920 V2-2 for (*i*–*ii*), and a Cyclops 6 (Turner Designs) with Cyclops 7 sondes (*i*, *iii*-*vi*) that are housed in water-tight flow-through chambers bolted to a concrete bulkhead containing water drawn (10 L/min) from high flow stator cooling pipes. Data are collected using an electronic data logger. The C6 is equipped with automatic anti-fouling brushes. Instruments are inspected, cleaned and calibrated every two weeks. At that time, data are downloaded from data loggers. Water samples (1.3 L) are collected to provide voucher samples of size-fractionated Chl-*a*, and ancillary measurements of high interest: nutrients (total phosphorus, dissolved SiO_2 and NO_3^-), major anions (SO_4^{2-}, Cl^-), and phytoplankton community composition using a FluoroProbe in the limnology lab of Twiss.

Upstream (Roving) Sampling for Hind-casting Model Development — Since the greatest scientific value is in the deployment of sensors at established, fixed sites in combination with roving stations, we sampled water quality at discrete upstream locations in July 2014 in order to support hind-casting model development (see Data Analysis and Modeling, below).

Data Analysis and Modeling

Water History Modeling — The high resolution data set collected at the dam will be used to hind-cast upstream water quality. This is the second stage of the project, which we are actively searching for funds to support. In brief, we will be using hydrodynamic modeling to determine the extent of water upstream that is sensed while traversing the hydropower dam sensor arrays. Water currents in the Upper St. Lawrence River are simulated every three hours using the Upper St. Lawrence River Forecasting System (USL, www.glerl.noaa.gov/res/usl), a real-time hydrodynamic model that is part of the Great Lakes Coastal Forecasting System by NOAA. Thus, for any sampling time we can obtain from Dr. Eric Anderson, NOAA-GLERL, environmental data that describes the physical conditions of the river. Using historical data from the time of any given sample collection, we can project the data to provide a time varying depth-averaged representation of the velocity field, which we denote as:

$$\boldsymbol{v} = \boldsymbol{u}(\boldsymbol{x}, t),$$

where $\boldsymbol{v}$ describes the velocity vector at time t at position $\boldsymbol{x}$ in the river (where 2-d vector $\boldsymbol{x}$ gives the position measured in UTM coordinates). Taking a Lagrangian perspective of the flow, we consider individual fluid parcels governed by that velocity field, where we observe the fluid parcel as it moves in time. Taking $\boldsymbol{a}$ to be the position of the fluid particle at time t_0, the position of the particle is given by

$$\boldsymbol{X}(\boldsymbol{a}, t),$$

and its evolution is related to the velocity field by the relationship

$$d\,\frac{\boldsymbol{X}(\boldsymbol{a}, t)}{dt} = \boldsymbol{u}(\boldsymbol{X}(\boldsymbol{a}, t), t), \tag{1}$$

such that the fluid parcel movement is governed by the velocity field. We use numerical integration to solve equation (1), where we also incorporate a stochastic term to account for dispersion of the flow.

***Ensemble of trajectories*:** For a particular sample i, taken at location $\boldsymbol{a}_i$, we choose an ensemble of locations, chosen from a bivariate normal distribution whose centered on the measured sample location. For each point in the ensemble, we can evolve its position backwards in time using the time varying flow field, looking 72 hours into the simulated flow. For each point in the ensemble we determine its velocity at each of those hourly time marks. In other words, for our sample location, we determined (a) where the water had come from over the previous 72 hours, and (b) what the velocity history of each water parcel was. We denote this ensemble of velocity measurements a$\{v_i\}$. This sample is interpreted as describing the distribution of velocity history for the water mass in the vicinity of the sample location. An example of this model output is provided in Figure 2.

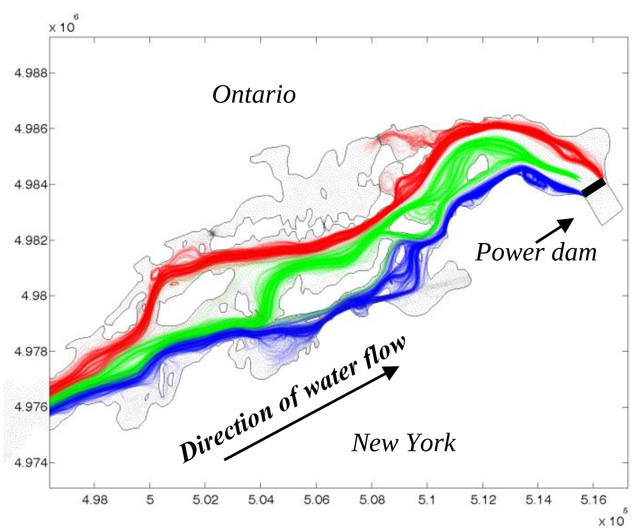


Figure 2. *Water trajectories upstream from the proposed sensor locations at the Moses-Saunders hydropower dam. Red = Canadian Shore (Unit 1), Green = main channel (Unit 17), blue = US shore (Unit 32). Latitude and longitude are UTM coordinates.*

***Modeling and Data Techniques* —** The key enablers with respect to the modeling and analytics aspects of this proposal are taken from three related data analysis approaches: time series analysis, geospatial analysis, and transport dynamics. The Lagrangian model of advection transport, coupled with the velocity information provided by the near-real time USL model allows us to perform a reasonably simple FORWARD calculation using equation (1), which (in principle) would be used to answer the question: "*If you know the water quality in the river at time* T *over region* R*, can you predict the characteristics at some future time at downstream locations?*". Our goal in this project is to invert that problem: "*Given information at a single location, can you predict characteristics over some upstream region at some previous time?*" We use an autosynchronization method to perform estimation and uncertainty propagation on this inverse problem.

From an information theoretic perspective, the time-lag inherent in the physical setting restricts the rate at which information from some upstream events can be transported to the sensor downstream. This information delay dictates that to predict water quality at an upstream location at the *present* time actually involves a two-step process: (1) using present-time sensor data to estimate upstream data at some previous time; and (2) using that first estimate, perform a forward time *prediction* to yield a value for an upstream location at a present time. The first component of that problem requires implementation of delay-synchronization techniques, which remains a cutting edge area of research of which we are fully aware. The forward prediction problem will be tackled via standard techniques for nonlinear time series prediction, where we also have research expertise. For cross-channel prediction, we note that the advection flow model allows the fixed point data stream to provide information about water quality only within a cone with vertex at the sensor location and spreading as we move upstream. Water quality events within that cone would (after temporal delay) be detected by the sensor, while outside that cone, we must use appropriate geospatial techniques to extend the region of prediction. We anticipate that Kriging will provide an appropriate estimator to extend the sensed data and the advection modeled data in the transverse direction.

Model validation for upstream spatial, temporal future, and transverse estimates will be critical to refining the full analytic approach. As such, the roving (upstream discrete) measurements provide critical information. We note that these models are based on Bayesian statistical approaches. As such, although the predicted value results from a maximum likelihood estimate, these computations can also estimate variance. This uncertainty estimate is a critical deliverable of the modeling process. As such, an associated goal of the modeling effort is to provide appropriate scientific visualization via “uncertainty quantification maps” that illustrate our true state of knowledge over both the spatial and temporal regimes. For the model data to be useful for decision making and inference, the “quality” of the predicted values is critical to assessing “risk” of various action plans. Often, the primary output from such models would be an “Expected Value” with a confidence interval around that value. We note that the stochastic nature of the flow dictates that it is most reasonable to think of the water conditions as having a “distribution” of values, represented via prediction intervals. The theory of prediction interval is well developed for both normally distributed and non-parametric data, where we may apply standard statistical techniques.

Project deliverables and status:

This project intends to make a notable contribution to the development of smart infrastructure in the Great Lakes-St. Lawrence River system. Through rational geographic sensor array locations and common data management protocols it seeks to document and communicate to decision makers, in a cost-effective manner, the environmental conditions in the St. Lawrence River.

1. **Deliverable:** High resolution water quality monitoring data set (365 days per year) archived and freely available to users via web-based portals.
    a. **Status:**
        i. **Array:** The array has been operating almost continuously since June 17, 2014. The unit was shut down November 7, 2014 for unexpected maintenance by NYPA of Unit 32 and it was brought back on line in February 2, 2015. The array ran until April 24, 2015. The C6 was sent back to the manufacturer (Turner Designs) for maintenance covered by warranty and will be back on line in the first week of June, 2015. We have resources to maintain basic sensor maintenance and array operations until June 2016.
        ii. **Data:** Data are currently accessible on-line (Google Documents). All data collected are compiled into text files that are available upon request to mtwiss@clarkson.edu. Data will be available via GLOS (see below) in the near future.
2. **Deliverable:** Mathematical modeling tool for establishing hind-casting capabilities of static sensor arrays locations in fluvial systems.
    a. **Status:**
        i. **Modeling:** We have data collected from discrete locations upstream that targeted the main channel and the nearshore, in order to show hind-casting ability to detect Oswegatchie River inflow and its impact on nearshore water quality. More data for extreme events are needed, e.g. high Oswegatchie flow resulting from spring freshet, or extreme weather events such as heavy rains.

Personnel involved with research project

Undergraduate students:

1. Faith Neff (Humboldt State University, 2015), summer NSF-REU participant at Clarkson University
2. Lindsay Avolio (Clarkson University, 2015), research assistant (September – January 2014)

Graduate Student:

1. Anthony Russo (Environmental Science and Engineering program, Master of Science, Clarkson University)

Publications:

1. **Website:** http://www.clarkson.edu/ise/great_rivers1/index.html

1. **Conference Poster Presentations**
    a. Neff, F.C., Sprague, H.M., Skufca, J.D., Twiss, M.R., American Geophysical Union Fall Meeting 2014, "*Water Quality Monitoring of the Upper St Lawrence*

River Using Remote Sensor Arrays Placed in a Hydropower Dam Combined With Hydrodynamic Modeling," American Geophysical Union, San Francisco, CA, (December 8, 2014).

b. Russo, A.D., Neff, F.C., Sprague, H.M., Loftus, S.E., Skufca, J.D., and Twiss, M.R., International Association for Great Lakes Research Annual Meeting, "*Water Quality Monitoring of the Upper St Lawrence River Using Remote Sensor Arrays Placed in a Hydropower Dam Combined With Hydrodynamic Modeling*", International Association for Great Lakes Research, Burlington, VT, (May 26, 2015).

Data Usage

1. **Eel migration:** Data collected during the 2014 eel migration (upstream) season were shared with V. Tremblay, Project Manager-Environment at AECOM (Trois-Rivières QC), the environmental consulting firm under contract with NYPA to operate the eel ladder on the New York side of the Moses-Saunders power dam.
2. **Undergraduate education:** Data collected from June to October 2014 was used as the base of an assignment in Limnology (BY 430 & BY 530) for students to develop skills in data analysis of large data sets related to water quality change as a function of time series.

Collaborations developed

1. **To enhanced capacity:** We have leveraged the opportunity to set up this sensor array to attract other researchers to contribute instrumentation to the array. To date we have acquired a nitrate sensor (optical [UV]; Satlantic) from G.L. Boyer (SUNY-ESF) that we are preparing for installation at Unit 32. At upgraded specific conductivity and temperature probe that includes an optic dissolved oxygen sensor has been included in a FEMRF proposal by J. Farrell (SUNY-ESF) for use at Unit 32.
2. **To increase data availability:** We have been contacted by the Great Lakes Observing System (GLOS) and invited to contribute our data to the GLOS data portal, which is our ultimate objective for data dissemination.
3. **Industrial partnership:** The New York Power Authority is a key partner in this smart infrastructure project. NYPA is committed to participating in scientific study of environmental issues affecting its industry, to regularly measure the environmental performance and share these results with the public, and to incorporate stakeholder and community input for responsible use of the water associated with its projects.

Examples of observations from data collection

Collecting data at one minute intervals provides a rich data set that can be used to relate observations to forcing functions. For demonstration purpose two topics are presented briefly here.

Cyanobacterial blooms: The late summer Cyanobacterial bloom that occurs in the St. Lawrence River was not detectable in 2014 by observations made on the surface but instead by the dispersal of this phytoplankton biomass in the water column (Fig. 3A). Normally, Cyanobacterial blooms are brought to attention by the public who note these scums accumulating on the surface of lakes and rivers and notify authorities responsible, the NYSDEC. Here, we show that the regular Cyanobacterial bloom that occurs in lakes and rivers in our region due to natural forcing functions (such as the grazing resistance Cyanobacterial colony formation) in late summer did occur. We now have a record of this bloom and the nutrients that it consumed (Fig. 3B) and can now compare it with subsequent annual blooms.

Tributary inputs: The Oswegatchie River that flows from the Adirondack Mountains is high in CDOM, compared to the clear waters of the St. Lawrence River that drains Lake Ontario. On July 17, 2014 water was sampled from the nearshore region (2 m isopleth) and the main channel (as defined by hydrodynamic modelling of the river (Fig. 2). CDOM was greater in concentration in the nearshore and lower in the main channel, with instances of high CDOM concentration in the nearshore attributed to low flow by high CDOM-rich tributaries along the shore line (Fig. 4). The flow from the Oswegatchie River and its high CDOM concentration is the dominant input of CDOM into the nearshore region (Fig. 5). However, the high temporal resolution of measurements that are made at Unit 32 shows that other forcing functions such as sunlight strongly influences apparent CDOM concentrations (Fig. 6).

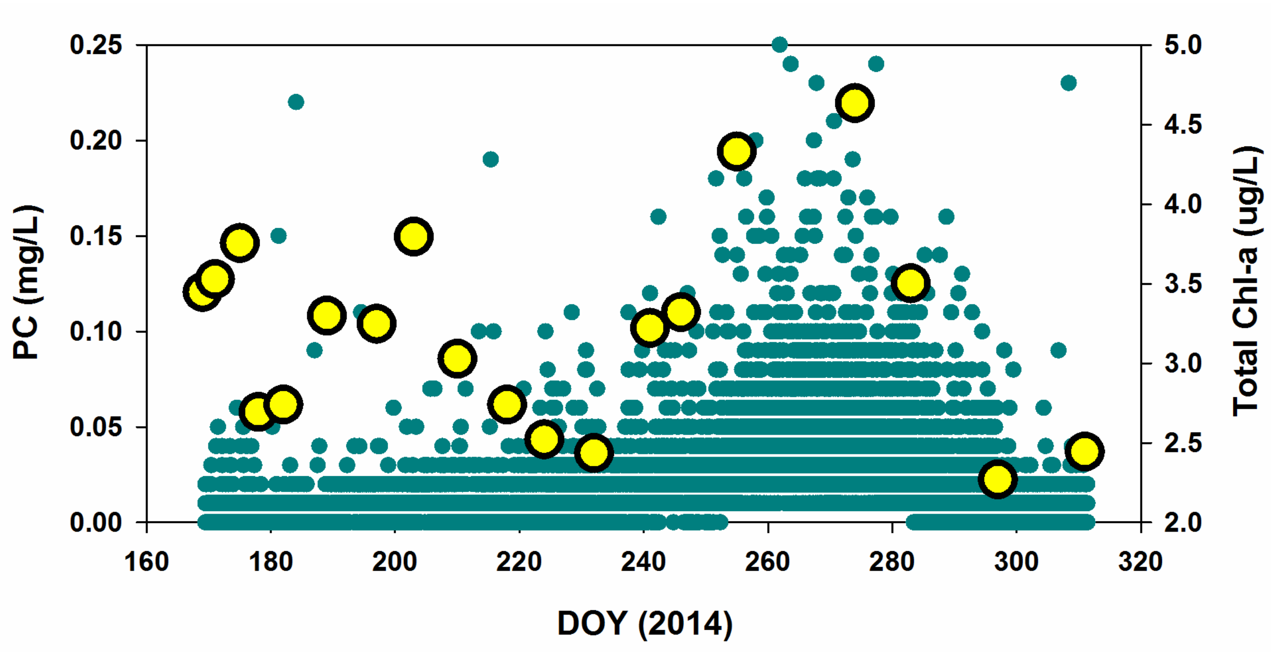
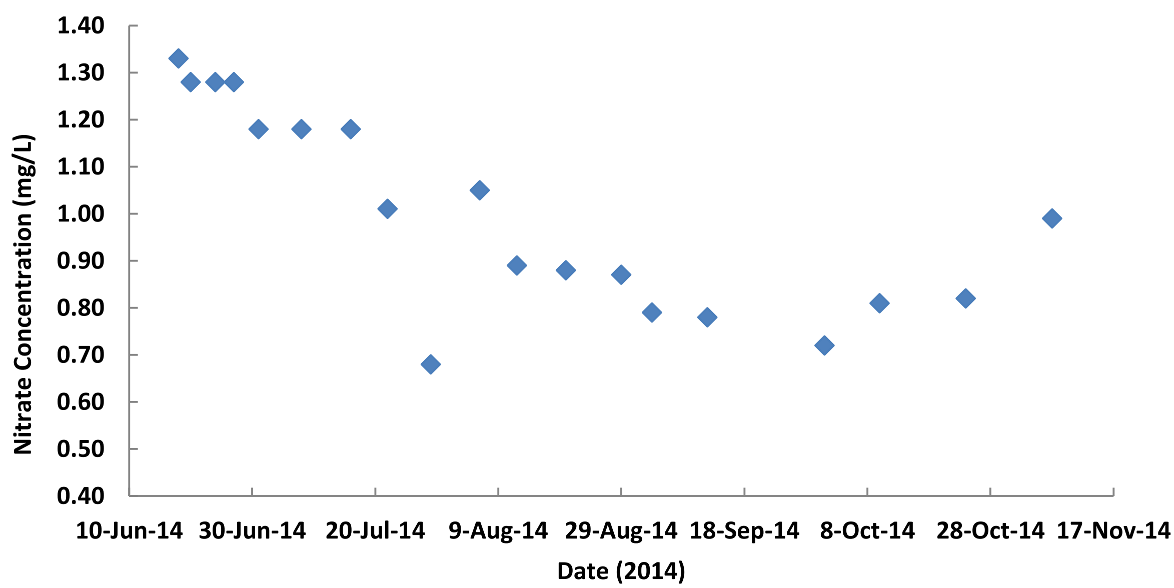


Figure 3A. Cyanobacteria (blue-green algae) increase in late summer 2014 as indicated by phycocyanin (PC) measured in situ and total chlorophyll-a (Chl-a) measured by acetone extracted pigment from grab samples collected at the sensor array in the power dam on days of maintenance and cleaning. **Fig. 3B.** (below) Decrease in dissolved (<0.2 µm) nitrate levels concomitant with the late summer cyanobacterial bloom.



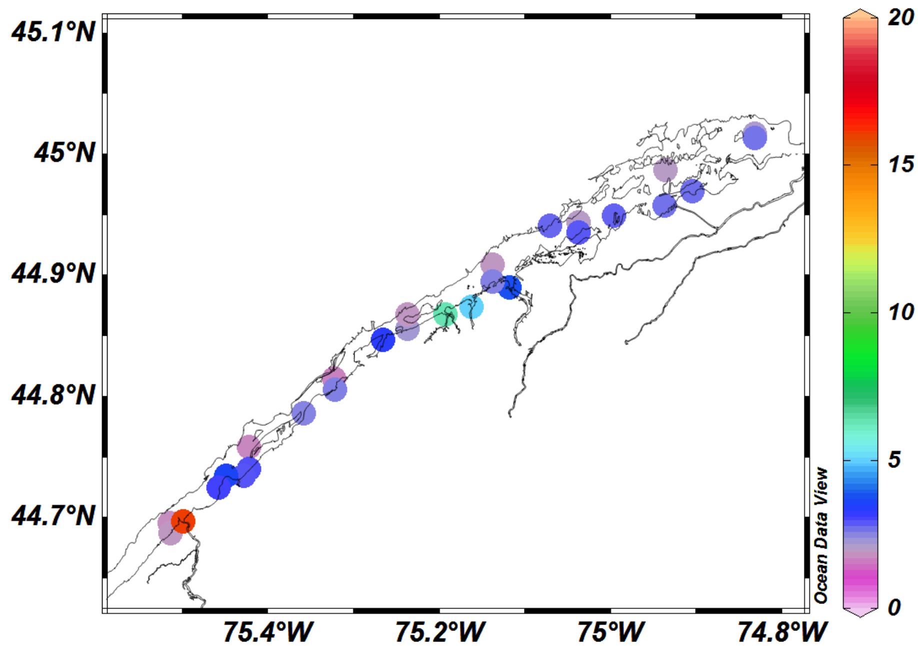


Figure 4. CDOM measured in grab samples collected on 17 July 2014 (DOY 198) from the nearshore (2 m isopleth) and main channel of the Saint Lawrence River from the power dam location (top right) upstream to the Oswegatchie River (lower left).

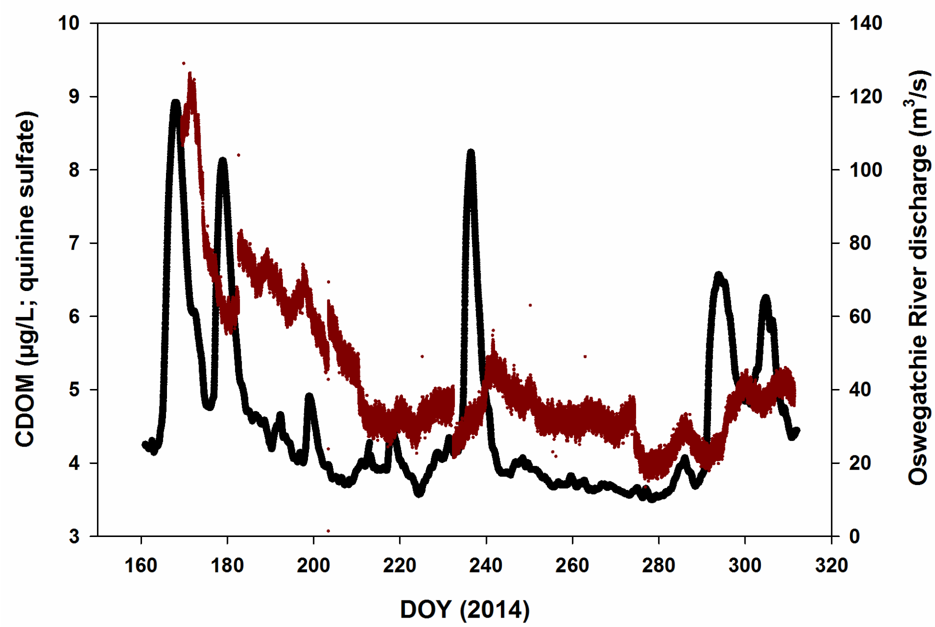


Figure 5. Relationship between discharge (black line) from the Oswegatchie River (high in CDOM) with CDOM measured in the nearshore waters at the Moses-Saunders power dam.

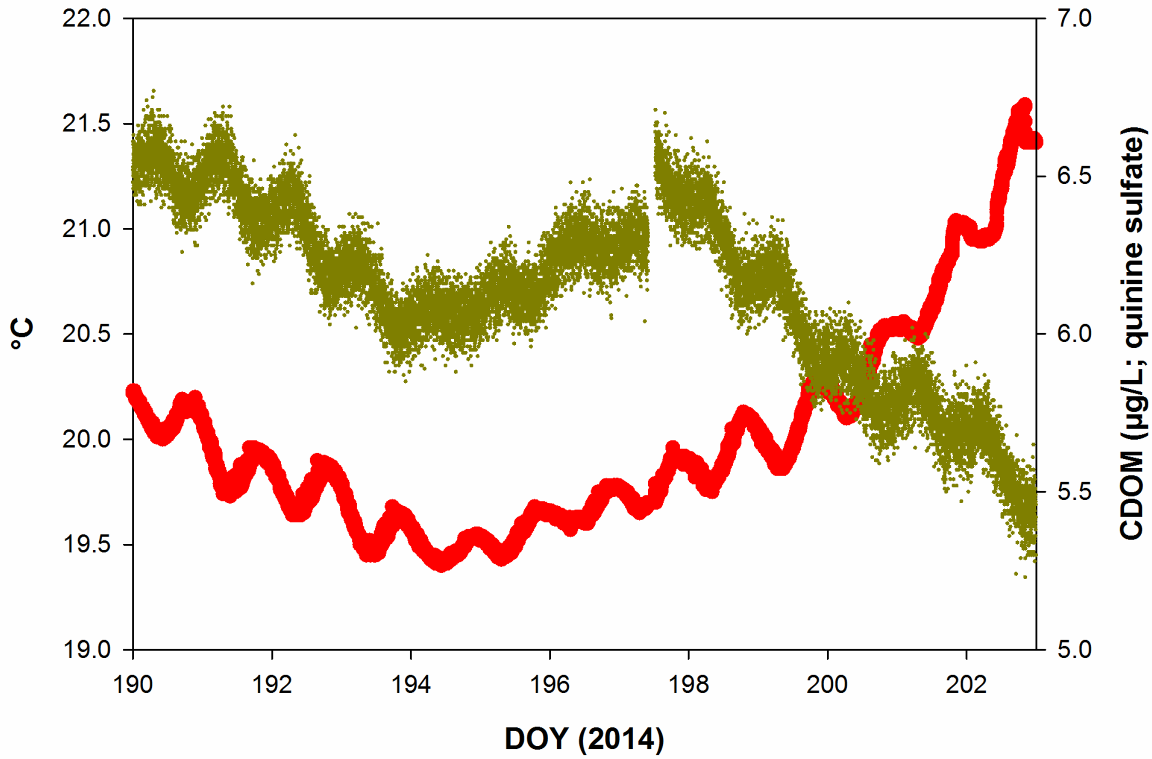


Figure 6. Relationship between daylight and in situ CDOM fluorescence. Water temperature in the nearshore zone is strongly influenced by the time of day, due to slight warming by sunlight in shallow waters (note the daily fluctuations of 0.2 to 0.5 ºC). In contrast, apparent CDOM concentrations decrease during the day, likely due to photobleaching.

Integrating Green Infrastructure into the Land Use Regulatory Process through the City of Newburgh Conservation Advisory Council

Basic Information

Title:	Integrating Green Infrastructure into the Land Use Regulatory Process through the City of Newburgh Conservation Advisory Council
Project Number:	2014NY211B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	18
Research Category:	Social Sciences
Focus Category:	Law, Institutions, and Policy, Management and Planning, None
Descriptors:	None
Principal Investigators:	Jeffrey LeJava

Publications

There are no publications.

2015

Green Infrastructure Guide

Conservation Advisory Council

City of Newburgh, New York

1/1/2015

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Green Infrastructure Guide

Welcome to the **City of Newburgh Conservation Advisory Council Green Infrastructure Guide**. The purposes of this Guide are to (1) inform the City Council, Planning Board, Zoning Board of Appeals and public about the importance of green infrastructure and the potential for its increased use in Newburgh and (2) direct the Conservation Advisory Council in its decision-making to address certain environmental impacts from development and redevelopment in the City. The Guide provides narrative text as well as links to important resource documents, and other relevant information, to assist the CAC in its duties and educate others about green infrastructure.

The Green Infrastructure Guide:

- Begins with an overview of green infrastructure, including defining the term and explaining the environmental, social and economic benefits to communities that employ green infrastructure practices.
- It then examines the current use of green infrastructure in the City and discusses how the City has planned for and is working to implement green infrastructure. As part of this section, the Conservation Advisory Council sets forth its Green Infrastructure Policy to guide its review of development projects and its efforts to educate City officials and residents about the importance of using green infrastructure.
- Next the Guide highlights key green infrastructure approaches to address stormwater flows and urban air quality.
- Finally, it concludes with a list of important green infrastructure resources from New York State, federal agencies and other organizations.

Please be aware that this Green Infrastructure Guide is an evolving document. As green infrastructure practices are implemented and their effectiveness evaluated, the contents of this Guide will be improved to serve the needs of the City of Newburgh and enhance the City's environment.

Section I - What is Green Infrastructure?

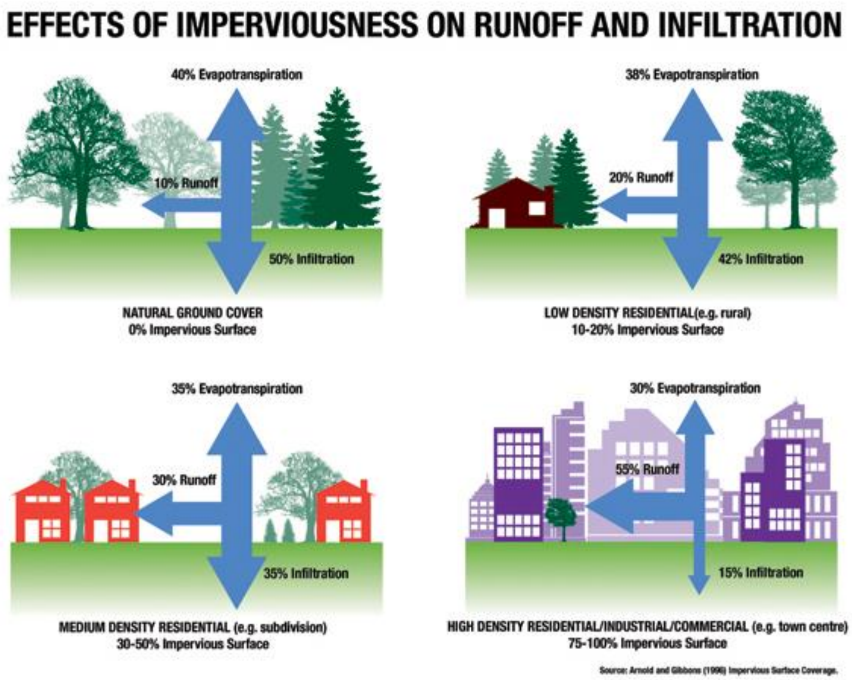
1. Green Infrastructure Defined

A significant portion of the City of Newburgh is hardscape, covered by buildings, parking lots, streets and other impervious surfaces, which prevent rain and snow from soaking into the ground. In a city like Newburgh, a typical city block generates more than five times the stormwater runoff produced on a woodland area of the same size. Stormwater travels over the land's surface, picking up contaminants like oil, fertilizer and other chemicals, and then flows either directly into streams, ponds and the Hudson River, or into storm sewers that then discharge into these same water bodies. In either case, the flow of contaminants into water bodies reduces water quality, negatively impacting both ecological and human health (see Figure 1 below).

This is made worse because areas of Newburgh are serviced by a combined sewer system (CSS). These sewers collect rainwater, domestic sewage, and industrial wastewater all in the same pipes. This combined sewage is then transported to the City's sewage treatment plant, or waste Water Treatment Facility (WWTF) before being discharged into the Hudson River. At times, during periods of heavy rainfall or snowmelt, the wastewater volume in a CSS exceeds the capacity of the wastewater treatment plant. When this happens, CSSs are designed to overflow and discharge excess raw wastewater directly into the Hudson River or the Quassaick Creek. This is known as a combined sewer overflow.

In some of the newer areas of the City, storm and sanitary sewer lines are separated; but even in those areas, because there is no place to discharge stormwater, the storm and sanitary sewer lines are reconnected and the combined sewage is directed to the WWTF.

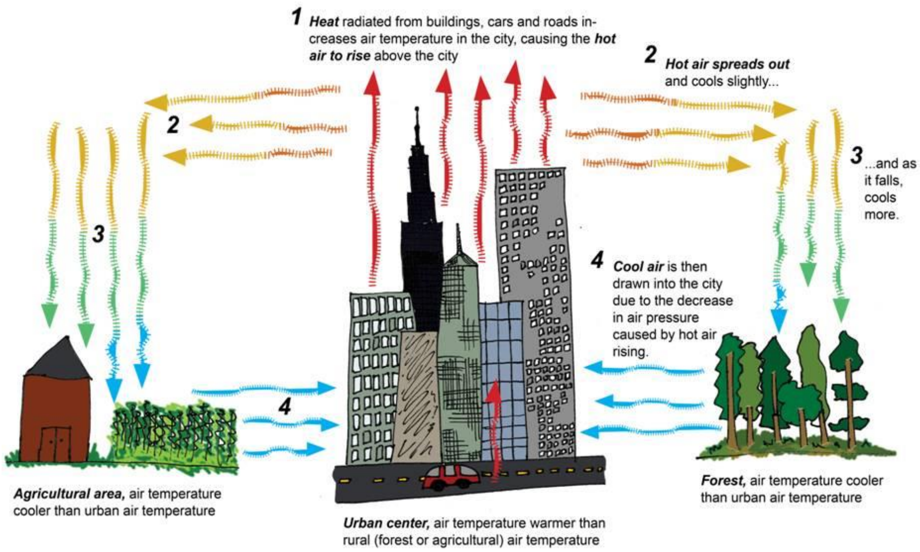
Figure 1:



Not only does stormwater carry pollutants into the water bodies like the Hudson River and the Quassaick Creek, the increased flow of this stormwater can cause flooding, deposition of silt, stream bank erosion, obstructions to fish passage, habitat loss, and loss of tree canopy along stream corridors. The damage wrought by this situation is likely to be exacerbated over the coming decades as climate change is predicted to produce storms of greater ferocity, generating larger volumes of rain over shorter periods of time.

These same developed areas also tend to increase urban air temperature relative to rural areas because concrete, pavement, and other impervious surfaces tend to absorb and retain heat, a circumstance known as the urban heat island effect (see Figure 2 below). With higher temperatures, the amount of energy needed to cool buildings is increased leading to greater energy demand. The higher temperatures also exacerbate human respiratory and other health related problems.

Figure 2:



(Source: https://bloomington.in.gov/documents/viewDocument.php?document_id=7061)

Green infrastructure refers to using and enhancing natural systems to absorb and filter pollutants from the air and water, protect communities from flooding and storm surges, reduce erosion, and create healthier, more sustainable urban environments. Green Infrastructure includes both landscape level strategies, such as the adoption of stream protection overlay zones with associated riparian buffers and flood plain designations; the creation of pocket parks within existing neighborhoods; and site specific practices such as green roofs, bioswales, tree planters and rain gardens among many others. In the context of this Guide, the CAC uses the term green infrastructure to include both landscape level and site-specific strategies and techniques that reduce stormwater flow and mitigate its impacts as well as strategies and techniques that seek to improve urban air quality. In some cases, particular green infrastructure practices, like green roofs, mitigate stormwater impacts and urban air quality simultaneously.

A term related to green infrastructure, but not synonymous with it is “low impact development” (LID). LID focuses on strategies to mitigate the adverse impact of site-specific development on the environment, principally with respect to stormwater. As the U.S. EPA notes, it “is an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible.”

As used by the City of Newburgh CAC in this Green Infrastructure Guide, LID principles aim to:

- preserve and recreate natural landscape features;
- restrict building on designated sensitive areas, such as wetlands and steep slopes;
- minimize impervious hardscape to create functional and aesthetically appealing site drainage;
- treat stormwater as a resource rather than a waste product; and
- appropriately design projects in harmony with their sites to reduce onsite stormwater generation.

2. <u>Benefits of Green Infrastructure</u>

The City of Newburgh CAC stresses the benefits of green infrastructure strategies for adapting to climate change, reducing stormwater flows, improving water quality, bettering air quality, lowering heat stress, creating greater biodiversity, conserving energy, sequestering carbon, preserving and expanding natural habitats for animals and plants, enhancing aesthetics, increasing property values, and improving the livability of our neighborhoods.

These benefits, particularly in an urban environment, are significant, varied and yet related. As the U.S. EPA notes, these benefits include:

Reduced and Delayed Stormwater Runoff Volumes – Green infrastructure reduces stormwater runoff volumes and lowers peak flows by using the natural retention and absorption capabilities of vegetation and soils. By increasing the amount of pervious ground cover (i.e., ground cover that allows rain and snow melt to soak into the soil), green infrastructure techniques increase stormwater infiltration rates, thereby reducing the volume of runoff entering the City's combined and separate sewer systems, and ultimately the Quassaick Creek and Hudson River.

Reduced Localized Flooding – By increasing the absorption of rain and snowmelt through various green infrastructure approaches, there is less stormwater available to pond in roadways, homes and businesses lessening localized flooding.

Enhanced Groundwater Recharge **–** The natural infiltration capabilities of green infrastructure technologies can improve the rate at which groundwater aquifers are 'recharged' or replenished. This is significant because groundwater provides about 40% of the water needed to maintain normal base flow rates in our rivers and streams. Enhanced groundwater recharge can also boost the supply of drinking water for private and public uses.

Stormwater Pollutant Reductions – Green Infrastructure techniques infiltrate runoff close to its source and help prevent pollutants from being transported to nearby surface waters. Once runoff is infiltrated into soils, plants and microbes can naturally filter and break down many common pollutants found in stormwater.

Reduced Sewer Overflow Events – Using the natural retention and infiltration capabilities of plants and soils, green infrastructure reduces the frequency of sewer overflow events by reducing runoff volumes and by delaying stormwater discharges. This benefit is critical in a city like Newburgh where people swim and recreate in the Hudson River, the discharge point for the City's wastewater treatment facility for the City's combined and separate storm sewers.

Increased Carbon Sequestration - The plants and soils that are part of the green infrastructure approach serve as sources of carbon sequestration, where carbon dioxide is captured and removed from the atmosphere via photosynthesis and other natural processes. By capturing carbon, the vegetation reduces the amount of carbon that may otherwise wind up in the atmosphere contributing to climate change.

Urban Heat Island Mitigation and Reduced Energy Demands - Urban heat islands form as cities replace natural land cover with dense concentrations of hardscape that absorb and retain heat. Additionally, tall buildings and narrow streets trap and concentrate waste heat from vehicles, factories, and air conditioners. By providing increased amounts of urban green space and vegetation, green infrastructure can help mitigate the effects of urban heat islands and reduce energy demands. Trees, green roofs and other green infrastructure can also lower the demand for air conditioning energy, thereby decreasing emissions from power plants.

Improved Air Quality - Green infrastructure relies on trees and vegetation in urban landscapes, which can contribute to improved air quality. Trees and vegetation absorb certain pollutants from the air through leaf uptake and contact removal. If widely planted throughout a community, trees and plants can even cool the air and slow the temperature-dependent reaction that forms ground-level ozone pollution (smog).

Additional Wildlife Habitat and Recreational Space - Greenways, parks, urban forests, wetlands, and vegetated swales are all forms of green infrastructure that provide increased access to recreational space and wildlife habitat.

Improved Human Health - An increasing number of studies suggest that vegetation and green space - two key components of green infrastructure - can have a positive impact on human health. Recent research has linked the presence of trees, plants, and green space to reduced levels of inner-city crime and violence, a stronger sense of community, improved academic performance, and even reductions in the symptoms associated with attention deficit and hyperactivity disorders. In a recent study from London, England published in the journal *Landscape and Urban Planning*, results showed that Londoners who live near more street trees get prescribed fewer antidepressants. According to the study, this association held true even when controlling for other local variables like socioeconomic status.

Increased Land Values - A number of case studies suggest that green infrastructure can increase surrounding property values. In Philadelphia, a green retrofit program that converted unsightly abandoned lots into "clean & green" landscapes resulted in economic impacts that exceeded expectations. Vacant land improvements led to an increase in surrounding housing values by as much as 30%. This translated to a $4 million gain in property values through tree plantings and a $12 million gain through lot improvements. Green infrastructure can also provide benefits to commercial properties where such approaches like street trees enhance the streetscapes within central business districts by making them more visually appealing and safer for pedestrians.

Increased Cost Efficiency – Green Infrastructure can also be cost effective. For example, a study released by the U.S. EPA in 2014 estimated that the City of Lancaster, PA would reduce its gray infrastructure capital costs by $120 million and reduce wastewater pumping and treatment costs by $661,000 per year by employing green infrastructure techniques within the City's combined sewer system (CSS) area. These benefits exceed the costs of implementing green infrastructure in the CSS area, which were estimated to range from $51.6 million if green infrastructure projects were integrated into planned improvement projects to $94.5 million if green infrastructure projects were implemented as stand-alone projects.

For more information on the public and private benefits of green infrastructure, please visit: http://water.epa.gov/infrastructure/greeninfrastructure/gi_why.cfm#WaterQuality

Section II - Green Infrastructure and the City of Newburgh

1. Planning for and Implementing Green Infrastructure in the City of Newburgh

Recognizing the importance of green infrastructure to the protection of the City's environment and public health, Newburgh seeks to integrate these practices into the City's fabric. In its 2008 sustainable comprehensive plan update, Plan-It Newburgh, the City established several goals and supporting strategies that, if implemented, will advance the use of green infrastructure. First, the City seeks to ensure the proper management of the natural environment to protect critical areas and conserve land, air, water and energy resources (Natural Resources Goal 2) for the purpose of maintaining their ecological functioning by:

- Prohibiting development in environmentally sensitive locations within the City limits;
- Including environmental protection and enhancement as an integral part of all City projects;
- Encouraging the use of Open Space or Cluster Zoning to focus new growth away from environmentally sensitive areas;
- Preventing or limiting development activity in hydrologically sensitive areas to protect a full range of wetlands and riparian functions; and
- Providing buffer planting requirements in the zoning code with an approved planting list.

Second, the City wants to reduce impervious cover and promote stormwater management best practices (Municipal Services Goal 3) by:

- Allowing the use of permeable surfaces for driveways and parking areas in residential and commercial developments; and
- Encouraging best management practices by minimizing and treating stormwater at its source, including the use of grass swales, rain gardens and green building techniques.

Third, the City desires to improve residents' quality of life by maintaining an equitable distribution of parks and open spaces and their interconnections (Natural Resources Goal 4). To achieve this goal the City recommends, among other strategies, to:

- Identify vacant City-owned properties and evaluate them for use as pocket parks or community gardens;
- Revise local ordinances to protect the City's open spaces through overlay zones or site plan requirements; and
- Include environmental protection and enhancement as an integral part of all development projects.

When implemented, the City's current Rezoning initiative will support these goals and strategies through a number of critical amendments, including the adoption of environmentally supportive zoning districts. First, the adoption of the Water Protection Overlay (WPO) District will promote the ecological health, biodiversity and natural habitats of and provide special protection to the City's creeks, stream corridors and waterbodies. The purpose of the WPO is to regulate land uses within or adjacent to a stream corridor or waterbody to protect water quality, biodiversity, scenic resources and reduce the risk of damage from flooding. The WPO includes and regulates all lands within 100 feet of the top of the bank on each side of the following waterbodies: Quassaick Creek and the ponds along its course:

(Muchattoes Lake, Stroock's Pond Harrison Pond); Gidneytown Creek and its tributary running parallel to route I-84; the unnamed stream Crystal Lake; Muchattoes Lake; the unnamed Stream that flows into Miller's Pond, through Crystal Lake and joins the Quassaick Creek at Little Britain Road east of Cerone Place; and that portion of the Hudson River that is not within the Planned Waterfront zoning district. Where there is no clearly defined bank, the district boundary shall be measured from the mean high-water line of the waterbody. All parcels having any part within the WPO will be subject to Site Plan review and approval, including recommendations from the City's CAC, and may not be exempted from that requirement.

Similarly, the establishment of the Conservation Development District (CDD) will use clustering and low impact development principles (discussed below) that encourage conservation of environmental resources in exchange for flexibility in bulk and area requirements and the potential for granting more intensive development if conservation goals are achieved. The primary conservation goals of the CDD are to: preserve and enhance open space, scenic views and environmentally sensitive features; protect steep slopes and flood plains by preserving vegetative cover to minimize the impacts of erosion and sedimentation; provide opportunities for on-site storm water management and groundwater recharge; encourage flexibility in the design of residential land uses that may not be permitted under traditional zoning regulations; promote a range of housing types; create on site recreation opportunities, and promote integration with neighboring land uses through trails and waterfront access points. Generally, density and dimensional standards in the CDD shall be approved by the City Planning Board based on the physical characteristics of the site; however, the number of dwelling units allowed in a CDD would be equal to the gross area of the CDD site, less environmental resources, divided by 3,000 square feet. The City Planning Board may grant a 20 percent density bonus if the proposed development substantially advances the environmental protection goals of the district. Importantly, development in the CDD also requires that 50 percent of the net land area of the parcel be preserved as open space by a permanent conservation easement or deed restriction. Like projects proposed with the WPO District, projects proposed within the CDD are subject to recommendations from the CAC.

While these landscape level land use approaches are vital to ensuring the continued integrity and ecological functioning of the City's existing open spaces, they must be supported by site-specific green infrastructure practices to address stormwater and urban air quality. These practices are beginning to occur within the City and will become standard practice as various City boards and commissions, including the Conservation Advisory Council, work to integrate green infrastructure approaches into local land use approvals.

2. <u>Requiring the Use of Green Infrastructure to Address Stormwater</u>

As noted above, developed areas disrupt the land's ability to absorb stormwater. Because land development is approved at the local level, federal and state laws require urbanized communities, like the City of Newburgh, to establish stormwater management programs whose goal is to maintain pre-development runoff conditions.

In New York State, the regulation of stormwater is administered by the Department of Environmental Conservation (DEC) under delegation by the U.S. EPA pursuant to the federal Clean Water Act. DEC implements the federal program through the issuance of two statewide General Permits under its State Pollutant Discharge Elimination System (SPDES):

- Under the SPDES General Permit for Stormwater Discharges from Construction Activity (GP-02-01), construction site operators must notify the state of any project disturbing one acre or more of soil, prepare a formal written Stormwater Pollution Prevention Plan (SWPPP) and adhere to the provisions of the plan during and after construction.

- Under the SPDES General Permit for Stormwater Discharges from Municipal Separate Stormwater Sewer Systems, or MS4s (GP-02-02), regulated MS4s, like the City of Newburgh, must establish stormwater management programs that reduce the discharge of pollutants to the maximum extent practicable, including reviewing and approving SWPPPs and regulating illicit discharges to the stormwater sewer system.

To help construction site operators comply with the requirements for managing stormwater during construction activities that disturb one acre or more of land, DEC developed the New York Standards and Specifications for Erosion and Sediment Control. The standards and specifications listed in the manual have been developed over time to reduce the impact of soil loss from construction sites to receiving water bodies and adjacent properties. The manual follows low impact development principles and provides designers with details on how to plan a site for erosion and sediment control and how to select, size, and design specific practices to meet these resource protection objectives.

Similarly, DEC published the New York State Stormwater Management Design Manual to assist project designers and regulated MS4 municipalities to satisfy their obligations under state regulations concerning post-construction circumstances. This manual, which DEC updated in January 2015, provides an overview on how to size, design, select, and locate stormwater management practices at a development site to comply with State stormwater performance standards. Because of the many benefits provided by green infrastructure, DEC amended the Design Manual in 2010 to prioritize the use of green infrastructure techniques. A number of the techniques described in Chapter 5 of the Design Manual are discussed more fully below.

The City of Newburgh is regulated as an MS4 and adopted its Stormwater Management Program in 2007. As part of this program, the City enacted a stormwater ordinance that establishes site and development standards that must be satisfied for subdivisions, site plans and construction projects where one acre or more of soil will be impacted. Under the ordinance, most development projects will require the preparation and approval of a Stormwater Pollution Prevention Plan (SWPPP), that, when implemented will result in no increase in peak stormwater discharge from the project site's predevelopment conditions as compared to its post development conditions. Projects subject to this requirement include:

- the subdivision of land;
- the approval of a site plan;
- the issuance of a building permit where greater than one acre of property will be impacted;
- the construction or extension of an existing City street or property, or private roadway; alteration of an existing drainage system or watercourse;
- redevelopment of existing sites; or
- such other project undertaken within the boundaries of the City or on or adjacent to property in which the City has an interest which poses an impact upon such property and which in the opinion of the City Engineer requires the creation and implementation of such plan to satisfy the purpose and objectives of the stormwater management program.

Where a SWPPP is required, the plan must be prepared in accordance with the New York State Stormwater Management Design Manual, including the emphasis on the use of green infrastructure. These plans are reviewed by the City of Newburgh engineer, who serves as the City's stormwater management officer. Upon review, a SWPPP is provided to the applicable land use board or City department for consideration as part of the development approval process.

3. The City's Current Green Infrastructure

SUNY-Orange, Newburgh Campus vegetated roof and rainwater harvesting system (Image courtesy of SUNY-Orange)

The City of Newburgh's parks, stream corridors, and urban tree canopy comprise larger, system-wide green infrastructure within the City. Currently, the City contains 341 acres of dedicated parkland, including approximately 32 acres of active parks and 309 acres of passive parks. The greater percentage of City-owned passive parkland, however, is the area surrounding Washington Lake, which is 270 acres located in the Town of Newburgh. These areas serve to reduce stormwater flows, reduce pollutant loads into the City's storm sewers and combined sewers, lessen urban air temperatures, provide wildlife habitat, and provide active and passive recreational opportunities for Newburgh residents. Please see the City of Newburgh Parkland Map here.

Newburgh also has several examples of site-specific green infrastructure practices. On the SUNY-Orange Newburgh campus, the college installed a vegetated roof as well as rain gardens to reduce stormwater flows from the development of Kaplan Hall. The green roof is located above the campus's parking garage and comprises part of an expansive plaza that overlooks the Hudson River.

Another site-specific project located within the City is found at the City's Water Treatment Plant. The Orange County Soil and Water Conservation District collaborated with Water Treatment Plant staff to install three separate rain gardens on the plant's property located at 493 Little Britain Road. The gardens serve to catch stormwater runoff from impervious surfaces such as plant's parking areas and prevent it from leaving the site and flowing into catch basins. Below are two pictures of the rain gardens after installation.

Rain gardens installed at the City of Newburgh Water Treatment Plant (Images courtesy of Orange County Soil & Water Conservation District

4. <u>The CAC and Green Infrastructure</u>

The Newburgh City Council has given the CAC a number of responsibilities that will advance the use of green infrastructure throughout the City. These responsibilities include:

- Advising various City agencies on greening the City's infrastructure;
- Studying problems and identifying the City's needs in connection with stormwater management, green infrastructure, sustainability and watershed protection;
- Making recommendations to the City Council as to desirable policy, promotion activities, and legislation concerning urban forestry and a tree maintenance program;
- Reviewing and making recommendations on any development application that seeks approval for the use or development of City's open space and natural resources;
- Providing an advisory consistency recommendation in accordance with the City's Local Waterfront Revitalization Program policy standards for any project within the Local Waterfront Revitalization Area;
- Reviewing and making recommendations on any application for sidewalk repair or replacement;
- Advising and making recommendations to the City's Superintendent of Public Works regarding the planting, pruning or removal of City trees. (6) Funding and training opportunities for tree maintenance and plantings and green infrastructure techniques; and
- Advising the Superintendent of Public Works, the Engineering Department, and the Water Department as to stormwater management relating to green infrastructure.

To facilitate these responsibilities, the CAC is taking the novel approach of working to identify some of the City's built environment that may be converted into green infrastructure (discussed specifically, below). The Natural Resources Inventory (NRI), which is currently being prepared, will highlight existing streets, medians, sidewalks, hard-packed underutilized and vacant lots, surface parking, and other impervious areas to be analyzed for their potential contributions to green infrastructure functions, including stormwater management.

As part of this NRI effort, the CAC will be incorporating the results of the *City of Newburgh Green Infrastructure Feasibility Report* prepared by eDesign Dynamics (EDD) with support from Hudson River Sloop Clearwater (Clearwater) and the Quassaick Creek Watershed Alliance (QCWA). EDD, Clearwater, and QCWA worked with the City of Newburgh to address local water quality concerns, the federal Clean Water Act, Combined Sewer Overflows (CSOs), natural hydrologic systems, and the potential role to be played by green infrastructure approaches for residents of Newburgh. EDD developed specific green infrastructure interventions in collaboration with stakeholders and are intended to complement the City's draft Long Term Control Plan (LTCP) to address combined sewer overflows (CSOs), regular and on-going road reconstruction work, and future land use planning. Of the many locations identified for possible green infrastructure practices, those with the highest potential to reduce CSOs and improve water quality in the Hudson or the Quassaick were chosen for further elaboration. The potential green infrastructure sites identified by EDD, along with its recommended green infrastructure techniques, will be incorporated into the CAC's NRI. These sites and recommended practices will serve as initial priority locations for the CAC when conducting project reviews.

In addition to identifying potential green infrastructure sites, the CAC has adopted a **Green Infrastructure Policy** that will guide its review of those development projects that are brought before it. This policy recognizes the critical importance of green infrastructure to the protection and enhancement of the City's natural resources, the health of its residents, and the City's long-term, sustainable economic growth. Simultaneously, the policy recognizes that the CAC is an advisory body only and that its efforts to promote and encourage the use of green infrastructure, where otherwise not required by State law, will be based upon its ability to persuade the City Council, land use boards and residents of the benefits that will accrue to the City through green infrastructure's use.

To ensure that green infrastructure practices become integrated into the City's land use planning and approval processes, the Newburgh CAC advances the following **Green Infrastructure Policy** consistent with low impact development strategies and green infrastructure practices found in New York State:

1. ***Avoid Development Impacts:***
    a. Prioritize redevelopment of existing buildings;
    b. Promote infill development of vacant parcels where such parcels are not currently being used for community gardens or other open space uses;
    c. Where new development is to occur, employ Low Impact Development principles that preserve existing site natural resources and features such as wetlands, stands of trees, and natural topography; develop only in the least environmentally sensitive areas of the site; and use conservation design techniques.
2. ***Limit Site Impervious Surface:***
    a. Employ Low Impact Development principles to reduce the amount of impervious surface necessary to support site development, including appropriately limiting building footprints and reducing the number of parking spaces to support site use.
3. ***Manage Development Impacts:***
    a. Utilize a site's natural features and green infrastructure techniques to slow down stormwater runoff, promote infiltration and evapotranspiration, and minimize the need for the structural stormwater controls;
    b. Where appropriate, plant native trees and plants to increase a site's tree canopy and vegetation to improve local air quality.
4. ***Enhance the City's Natural Environment***
    a. Where the City is undertaking street or sidewalk improvements, look for opportunities to add to the City's tree canopy by planting new street trees and integrating specific green infrastructure techniques like bioswales and curb cuts that flow into tree pits.
    b. Look for opportunities to add green infrastructure practices to existing City buildings such as green roofs and green walls to serve as demonstration projects to City residents and developers.
5. ***Coordinate Intermunicipal Cooperation to Ensure Watershed Protection***
    a. Work with City of Newburgh departments, DEC's Hudson River Estuary Program, and other appropriate stakeholders to develop an intermunicipal hazard mitigation plan with adjoining municipalities to ensure the long-term protection of the City's water supply.

In light of the CAC's Green Infrastructure Policy, the Green Infrastructure Guide below highlights particular green infrastructure practices to reduce the generation of and impacts from stormwater as well as improve the City's local air quality.

Section III – Green Infrastructure Practices to Reduce Stormwater Flows and Mitigate its Impacts

As discussed above, green infrastructure to address stormwater includes a wide array of practices at multiple scales to manage and treat stormwater, maintain and restore natural hydrology and ecological function by infiltration, evapotranspiration, capture and reuse of stormwater, and establishment of natural vegetative features. Above, the Guide highlighted some of the municipal scale approaches that the City of Newburgh is likely to take through its eventual adoption of the Rezoning initiative. These include the protection of waterways throughout the City with the creation of a Water Protection overlay zone and the establishment of a Conservation Design District that relies on clustering and site design to preserve natural landscape features. Similarly, the City's emphasis on redeveloping its downtown core and waterfront by reusing existing buildings will serve to lessen development demand on the City's remaining open areas.

The green infrastructure practices introduced below focus on site- and neighborhood-specific practices and runoff reduction techniques and are drawn from Chapters 3 and 5 of the New York State Stormwater Management Design Manual. When implemented, these practices will result in stormwater runoff reduction that will protect and enhance the City's stream corridors and the Hudson River. These practices will also improve the visual environment of the City by adding new greenscape to the more developed portions of the City.

Green infrastructure techniques to address stormwater can be grouped into four broad categories:

- **Low Impact Development (LID) techniques**, such as preserving undisturbed site areas and natural features, reducing grading and site clearing, and siting structures in the least sensitive areas of a site – they reduce the amount of impervious surface to be placed on a parcel of land.
- **Infiltration techniques**, such as permeable pavements, disconnected downspouts, and rain gardens—they are engineered structures or landscape features designed to capture and infiltrate stormwater, reduce runoff volume, and treat or clean runoff.
- **Evapotranspiration practices**, such as green roofs, bioswales, trees, and other vegetation—they can reduce stormwater runoff volumes by returning water to the atmosphere through evaporation of surface water or through transpiration from plant leaves. Trees and shrubs can also filter air pollutants and improve air quality.
- **Capture and reuse practices**, such as rain barrels and cisterns—they capture stormwater for non-potable household uses, irrigation, or gradual infiltration.

Table 1, below, is drawn from Chapter 3 of the Stormwater Management Design Manual and lists many of the LID techniques that are to be used in the development of SWPPP where an acre or more of soil will be disturbed during construction activities:

Table 1 – Planning Practices for Preservation of Natural Features & Impervious Surface Reduction

Group	Practice	
Preservation of Natural Resources	Preservation of Undisturbed Areas	Delineate and place into permanent conservation easement undisturbed forests, native vegetated areas, riparian corridors, wetlands, and natural terrain.

	Preservation of Buffers	Define, delineate and place in permanent conservation easement naturally vegetated buffers along perennial streams, rivers, shorelines and wetlands.
	Reduction of Clearing and Grading	Limit clearing and grading to the minimum amount needed for roads, driveways, foundations, utilities and stormwater management facilities.
	Locating Development in Less Sensitive Areas	Avoid sensitive resource areas such as floodplains, steep slopes, erodible soils, wetlands, mature forests and critical habitats by locating development to fit the terrain in areas that will create the least impact.
	Open Space Design	Use clustering, conservation design or open space design to reduce impervious cover, preserve more open space and protect water resources.
	Soil Restoration	Restore the original properties and porosity of the soil by deep till and amendment with compost to reduce the generation of runoff and enhance the runoff reduction performance of practices such as downspout disconnections, grass channels, filter strips, and tree clusters.
Reduction of Impervious Cover	Roadway Reduction	Minimize roadway widths and lengths to reduce site impervious area
	Sidewalk Reduction	Minimize sidewalk lengths and widths to reduce site impervious area
	Driveway Reduction	Minimize driveway lengths and widths to reduce site impervious area
	Cul-de-sac Reduction	Minimize the number of cul-de-sacs and incorporate landscaped areas to reduce their impervious cover.
	Building Footprint Reduction	Reduce the impervious footprint of residences and commercial buildings by using alternate or taller buildings while maintaining the same floor to area ratio.
	Parking Reduction	Reduce imperviousness on parking lots by eliminating unneeded spaces, providing compact car spaces and efficient parking lanes, minimizing stall dimensions, using porous pavement surfaces in overflow parking areas, and using multi-storied parking decks where appropriate.

These practices are described more fully in Chapter 5 of the Stormwater Management Design Manual and may be found here.

The remaining green infrastructure techniques that infiltrate, evapotranspirate, capture and reuse stormwater are engineered practices that can be incorporated into site design to allow for site-level management of runoff. Together, these practices result in less stormwater runoff by promoting groundwater recharge, increasing water losses through evapotranspiration (the evaporation of water from plant leaves (transpiration) and evaporation of water from the land's surface) and emulating a site's preconstruction hydrology.

Table 2, below, adapted from Chapter 5 of the Stormwater Management Design Manual, lists a number of runoff reduction green infrastructure practices, provides a brief description of the practice and shows an image of the practice in use in New York State.

Table 2 – NYS Green Infrastructure Practices to Reduce Stormwater Runoff

Practice	Description	Image
Vegetated open swale Harrier Hill Park, Stockport, Columbia County, vegetated swale (Image courtesy NYS DEC)	The natural drainage paths, or properly designed vegetated channels, can be used instead of constructing underground storm sewers or concrete open channels to increase time of concentration, reduce the peak discharge, and provide infiltration.	
Tree planting / tree box Rome, NY street trees (Image courtesy NYS Environmental Facilities Corporation)	Plant or conserve trees to reduce stormwater runoff, increase nutrient uptake, and provide bank stabilization. Trees can be used for applications such as landscaping, stormwater management practice areas, conservation areas and erosion and sediment control.	
Disconnection of rooftop runoff (Image courtesy NYS Environmental Facilities Corporation)	Direct runoff from residential rooftop areas and upland overland runoff flow to designated pervious areas to reduce runoff volumes and rates.	

Stream daylighting for redevelopment projects Sawmill River, Yonkers, NY (Image courtesy http://frogma.blogspot.com)	Stream Daylight previously-culverted/piped streams to restore natural habitats, better attenuate runoff by increasing the storage size, promoting infiltration, and help reduce pollutant loads.	
Rain garden SUNY-Orange rain garden, Middletown, NY (Image courtesy NYS DEC)	Manage and treat small volumes of stormwater runoff using a conditioned planting soil bed and planting materials to filter runoff stored within a shallow depression.	
Green roof Beacon Institute Green Roof Beacon, NY (Image courtesy NYS DEC)	Capture runoff by a layer of vegetation and soil installed on top of a conventional flat or sloped roof. The rooftop vegetation allows evaporation and evapotranspiration processes to reduce volume and discharge rate of runoff entering conveyance system. In summer, depending on the plants and depth of growing medium, green roofs retain 70-90% of the precipitation that falls on them; in winter they retain between 25-40%.	
Stormwater planter Portland, OR (Image courtesy NJ Future)	Small landscaped stormwater treatment devices that can be designed as infiltration or filtering practices. Stormwater planters use soil infiltration and biogeochemical processes to decrease stormwater quantity and improve water quality.	

Rain tank/Cistern Buffalo, NY rain barrel (Image courtesy Buffalo Niagara Riverkeeper)	Capture and store stormwater runoff to be used for irrigation systems or filtered and reused for non-contact activities.	
Porous Pavement Beacon Institute porous pavers Beacon, NY (Image courtesy NYS DEC)	Pervious types of pavements that provide an alternative to conventional paved surfaces, designed to infiltrate rainfall through the surface, thereby reducing stormwater runoff from a site and providing some pollutant uptake in the underlying soils.	

Section IV – Green Infrastructure to Address Urban Air Quality

A. Urban Forests

As discussed above, urbanized communities like the City of Newburgh experience air quality issues, including increased air pollutant emissions and increased temperatures that are not found in less developed areas. Green infrastructure, in the form of urban forests, will play an important role in addressing these concerns.

Urban neighborhoods are protected by tree canopies covering streets, sidewalks, private lots, parks, and other private and public lands. Similarly, trees on private lots shade residences, workplaces, and shopping areas. These trees are sometimes called urban forests and they constitute a large percentage of a community's green infrastructure.

Urban forests help reduce energy consumption. With leaves on, the urban tree canopy shades buildings, sidewalks, streets and other structures keeping them cooler during the warmer months, which reduces the need for air conditioning. Trees placed in the proper location along with correct tree species selection, can shelter buildings from cold winds in winter months reducing heating costs. Taken together, these uses of trees lower overall energy consumption in urbanized communities.

Urban forests also sequester carbon that might otherwise contribute to global climate change. Between 1990 and 2012, the amount of carbon sequestration by urban trees increased by 46.3 percent in the

United States. While the total amount of sequestration contributed by urban trees is small compared to that in rural areas, it remains important. In New York City, its 5.2 million trees remove over 42,000 tons of carbon each year and store about 1.35 million tons of carbon valued at $24.9 million.

Additionally, trees in urbanized communities also have positive effects on human health. As noted by the New York State DEC, “studies have found that exposure to trees reduces the symptoms of stress and depression, can aid in the recovery from surgery, and reduce the incidence of domestic violence.” In a recent study from London, England published in the journal *Landscape and Urban Planning*, results showed that Londoners who live near more street trees get prescribed fewer antidepressants. According to the study, this association held true even when controlling for other local variables like socioeconomic status.

While land use regulations and project approvals can be used to preserve urban trees, efforts need to be made to plant new trees. For example, New York City initiated its MillionTreesNYC program in 2007, a citywide, public-private initiative that seeks to plant and care for one million new trees across the City's five boroughs over the next decade. New York City hopes that by planting one million additional trees, it can increase its urban forest by 20 percent, while achieving the many quality-of-life benefits that come with planting trees.

As part of its Natural Resource Inventory, the City of Newburgh CAC is currently conducting a tree inventory. This inventory will quantify the City’s trees to determine the extent of the City’s urban tree canopy, the number of tree species located within the City, and the value of environmental benefits provided by those trees. This information will aid the CAC in determining which areas of the City should be targeted for increased tree plantings as street and sidewalk improvements are constructed by the City.

B. Green Roofs and Walls

Augmenting the benefits of urban forests, vegetation on buildings can enhance green infrastructure in urbanized environments like the City of Newburgh. Green roofs, sometimes also called eco-roofs or vegetated roofs, are specially designed rooftop gardens or lawns that retain stormwater, provide habitat, improve building efficiency, and increase a community’s aesthetics.

Importantly, green roofs and walls also improve urban air quality. Through the daily dew and evaporation cycle, plants on vertical and horizontal surfaces are able to cool urbanized areas during hot summer months. They reduce the Urban Heat Island (UHI) effect through the vegetation’s absorption of light that would otherwise be converted into heat energy. Additionally, by covering rooftops that are often black, the ability of those rooftops to absorb and retain the heat from the sun is lessened. In turn these circumstances reduce the demand for building cooling and the electricity needed to power cooling systems. Like urban forests, green roofs also capture airborne pollutants and atmospheric deposition, filter noxious gases and sequester carbon.

Green walls, which are similar to green roofs, but are located on the facades of buildings, provide similar air quality benefits. A green wall is a vertical garden that is pre-planted in panels and then attached to the facade of the building. The plants stay in their vertical positions because their root structures are anchored in 2-4 inches of soil kept within the panel. As with green roofs, green walls capture airborne pollutants and atmospheric deposition, filter noxious gases, sequester carbon and reduce ambient air temperatures.

Where appropriate, the CAC will look for opportunities to promote the use of green roofs and walls during the review of site plans and other land use approvals where the CAC is to provide its recommendations to the appropriate land use board.

Section V – City of Newburgh CAC Green Infrastructure Technical Recommendations

One of the CAC's primary responsibilities is to review certain land development applications and all permit applications for sidewalk repair or replacement. In the context of these project reviews, the CAC will evaluate permit applications consistent with its **Green Infrastructure Policy**. In accordance with Paragraphs 3 and 4 of the Policy, the CAC seeks to enhance the City's environment by having project applicants install appropriate green infrastructure practices, particularly new street trees and their tree pits.

To assist project applicants in addressing this policy, the CAC incorporates a number of the recommended Green Infrastructure Design Guidelines prepared on behalf of the City of Newburgh by eDesign Dynamics as part of its *Green Infrastructure Feasibility Report* along with practices recommended by DEC.

1. <u>Sizing Criteria</u>

Sizing of green infrastructure should be based on a volume associated with a standard rainfall event. It is recommended that GREEN INFRASTRUCTURE practices in Newburgh be sized to accommodate the NYSDEC Water Quality Volume (WQv). NYSDEC defines the WQv as the volume of runoff resulting from the 90th percentile rainfall event, which
for Newburgh is estimated to be 1.1 inches of rain. As per DEC:

$$WQv = [(P)(Rv)(A)] / 12, \text{ where:}$$
$$Rv = 0.05+0.009(I); \; I = \text{Percent Impervious Cover; minimum } Rv=0.02$$
$$P = 90\text{th percentile rainfall event in inches} = 1.1 \text{ inches}$$
$$A = \text{catchment area in acres}$$

Using the WQv to size green infrastructure allows for a significant reduction in runoff from entering the combined sewer system, with approximately 90% of rainfall events being completely managed and larger events (greater than 1.1 inches) being partially managed. The WQv also has the added benefit of allowing green infrastructure systems to treat stormwater in separate sewer systems, provided a 24-hour extended detention, as per DEC's guidelines. Note: the WQv is a target volume, and should not be used as the sole criteria in evaluating green infrastructure opportunities. Green infrastructure systems are still effective when the WQv cannot be fully managed. Additionally, providing excess capacity beyond the WQv may not always be cost-effective, but can provide additional storage and opportunity to expand the contributing area. Finally, when designing green infrastructure practices that require excavation, a maximum depth of five feet below existing grade shall be used to avoid high construction costs associated with shoring.

2. Buried Utility Setbacks

As construction of green infrastructure systems generally involves excavation and occasional use of buried pipe, a setback from existing buried utilities is typically required. To determine the location of these utilities a survey shall be performed on site, as part of the initial feasibility analysis. In some cases the utility may possess an easement to allow for their own excavation and repair. Examples of subsurface infrastructure include gas, electric, cable, water, sewer, and telecom. A utility setback of three feet from the lateral extent of the utility is recommended, though in some cases, such as high-tension electrical lines, the setback can be as high as five feet. When developing its guidelines, Newburgh should establish a convention that meets with the approval from all relevant utility owners.

3. Foundation Setbacks

Where green infrastructure systems intend to promote infiltration (ie: unlined retention-type systems), a setback from existing building foundations or other subsurface utility vaults should be established in order to prevent intrusion, basement flooding and corrosion. These setbacks vary nationally from between five and twenty feet, though ten feet is becoming standard. In some dense urban areas, the setback can be reduced to five feet with the use of a vertical barrier lining the sides of the infiltration-based system to limit the lateral movement of water. This technique, however, has not yet been demonstrated to be effective. When the green infrastructure practice does not allow for infiltration (ie: pure detention systems with complete liners), setback from foundations should be based on structural concerns rather than risk of flooding.

4. Depth to Bedrock or Seasonally High Water Table

Most sets of guidelines require that infiltration-based green infrastructure remain a certain distance above bedrock and above the seasonally high water table. These conditions are determined using a geotechnical probe or drill rig under the guidance of a professional geologist or engineer. At the time of drilling, it is also common to perform an infiltration test on the in situ soils at the depth prescribed for the bottom of the green infrastructure. The NYSEFC specifies that green infrastructure must be installed at least three feet over bedrock and seasonally high water table.

5. Guidelines for Green Infrastructure in the Right-of-Way

When designing green infrastructure in the Right-of-Way (ROW) it is important to adhere to all local and state agency regulations (see Regulatory Approval and Permits below). In addition, minimum setbacks are recommended to allow for clear access of pedestrians and vehicles, and protection of existing structures. The most important consideration for designing green infrastructure in the ROW is allowing a five foot minimum clear path for pedestrian access on sidewalks. For high density neighborhoods the minimum clearance can be greater. Table 1 below lists suggested minimum distances for designing and constructing green infrastructure in the ROW.

Table 3 – Suggested Setbacks for Green Infrastructure Practices Located in the Right-of-Way

Recommended minimum distance/setback	From
Five feet	Existing structures and street furniture such as traffic signs, street lighting, fire hydrants, benches etc.

Five feet	Pedestrian ramps.
Five feet	Legal curb cuts/driveways.
Five feet	Property lines.
Three feet	Subsurface infrastructure including gas, electric, water, sewer, telecom, etc.
Drip line	Existing tree canopies.
Ten feet	Existing building foundations

6. Soil Tests

When geotechnical borings are to be performed, it is advisable to perform waste classification testing of the in situ soil at elevations that would fall within the proposed green infrastructure. Since green infrastructure designs often require replacing existing soil with gravel and engineered soil, the cost of disposal of excavated soils should be considered in advance. In urban areas, legacy contamination may trigger costly disposal fees when certain constituents exceed safe concentrations. Environmental laboratories are equipped to perform a set of tests based on the local or state regulatory requirements for solid waste disposal. At least one composite sample taken from the proposed location should be tested well in advance of construction.

7. Infiltration Tests

A number of protocols are available for testing the infiltration capacity of undisturbed soils. In urban areas it is common to find a large quantity of fill material placed over the natural soil, making it difficult to assess the capacity at points below the surface. When geotechnical work is to be performed, it is common to require an infiltration test at the elevation of the bottom of the proposed green infrastructure. Infiltration can be measured using the standard protocol described in ASTM D6391-11. Alternatively, some municipalities recommend performing the test in an open pit. The City of Newburgh will need to select its preferred method, based on local costs and conditions, and establish a precise protocol and minimum infiltration rate for infiltration-based systems.

8. Tree Species

When planting trees, the tree species and size should be appropriate for location and soil type among other factors. The City of Newburgh lies within the US Department of Agriculture Tree Hardiness Zone 6a. Given this location, and based upon the expertise of the DEC, the CAC recommends that the following species of trees be considered:

[Insert list of tree species currently recommended by CAC]

For further information about performing a tree site assessment and selecting an appropriate tree species, please visit: http://www.hort.cornell.edu/uhi/outreach/recurbtree/pdfs/~recurbtrees.pdf

9. Tree Pits

Finally, tree pits provided for street trees should adhere to the following specifications:

(a) **Tree Pit Size** – Tree pits should be as large as possible to allow for ample growing space for tree roots and crown. The overall width of a sidewalk can limit the size of a tree pit. Ideal tree pit sizes are 4 feet by 10 feet or 5 feet by 10 feet where space allows. If the recommended tree pit size does not match the builder's pavement plan, the plan must be revised.

(b) **Backfill** - Material shall consist of natural loam topsoil with the addition of humus only, and no other soil type, such as a sand or clay soil type, shall be accepted. Topsoil must be free from subsoil, obtained from an area which has never been stripped. It shall be removed to a depth of one (1) foot, or less if subsoil is encountered. Topsoil shall be of uniform quality, free from hard clods, stiff clay, hardpan, sods, partially disintegrated stone, lime, cement, ashes, slag, concrete, tar residues, tarred paper, boards, chips, sticks or any other undesirable material. If a truckload of topsoil is considered by the Agency to contain too much undesirable material to be corrected on the site, the entire truck load shall be rejected. No topsoil shall be delivered in a frozen or muddy condition. Topsoil shall comply with the following requirements:

i. Organic Matter. Must be between eight (8) and twelve (12) percent by weight, as determined by the Dry Combustion Method for Total Carbon and Organic Carbon (using a multiplying factor of 2) as described in Methods of Soil Analysis, #9, Part 2, 2nd ed. published by the American Society of Agronomy. The organic content shall not exceed fourteen percent (14%).
ii. pH range. Shall be 6.0 to 7.0 inclusive.
iii. Sieve Analysis (by Wash Test, ASTM Designation C-117). Passing 2" sieve (100%); Passing 1" sieve (95% to 100%); Passing #4 sieve (90% to 100%); Passing #100 sieve (30% to 60%).
iv. Clay. The test method to measure the clay content of the soil shall be ASTM D 422.

The Engineer reserves the right to reject topsoil in which more than 60% of the material passing the No. 100 U.S.S. Mesh sieve consists of clay as determined by the Buoyoucous Hydrometer or by the decantation method. All percentages are to be based on dry weight of sample. When the topsoil otherwise complies with the requirements of the specification but show a deficiency of not more than one (1) percent in organic matter, it may be incorporated when and as permitted by the City Engineer. Electrical Conductivity shall be less than 1500 mhos/cm. A higher level would indicate excessive salt content. The testing method must be the saturated paste method.

At final inspection if soil does not appear to meet specifications you will not receive a final sign-off of your permit. If directed, topsoil which varies only slightly from the specifications may be made acceptable by such corrections as the City Engineer deems necessary.

(c) **Mulch** – Shredded bark mulch shall be a natural forest product of 98% bark containing less than 2% wood or other debris. It shall be of White or Red Fir and/or Pine bark of a uniform grade with no additives or any other treatment. Size of bark shall be from 5/8" to 1-1/4".The pH factor should range from 5.8 to 6.2. Shredded bark may also be used.

(d) **Finishing** – Paving blocks, installed in the manner described below, are required within each sidewalk tree pit, unless a tree pit guards is going to be installed. Please note that the City will take action if the tree guard or paving endangers the long-term health and survival of City-owned trees. The City does not allow tree grates to be installed around newly planted or existing trees.

(e) **Paving Blocks**

i. Materials – Granite Block Pavers: Granite blocks shall be new or used and shall be cut from fine to medium grained sound and durable granite. The granite shall be reasonably uniform in quality and texture throughout and shall be free from an excess of mica and feldspar and from seams, scales or evidence of disintegration. If used blocks are utilized they shall be clean, free from mortar, asphalt, etc.

ii. Blocks shall be fairly rectangular in shape and shall be not less than four (4) inches nor more than twelve (12) inches in length; not less than three (3) nor more than five (5) inches in width; not less than three (3) nor more than five (5) inches in depth. The blocks shall be cut so that opposite faces will be approximately parallel and adjoining faces approximately at right angles to each other. Granite blocks shall be so dressed that they may be laid with one (1) inch joints. All blocks shall have one reasonably smooth split head.

iii. Installation – Paving blocks shall be installed using a sand cushion. The sand shall consist of clean, hard, durable, uncoated stone particles, free of lumps of clay and all deleterious substances and shall be so graded when dry, one hundred percent shall pass a ¼ inch square opening sieve; not more than thirty-five percent by weight shall pass a No. 50 sieve. Sand shall conform to ASTM C-33. Trim and tamp the subgrade to smooth, uniform lines prior to placing the pavers. The pavers shall be laid on a sand cushion with a minimum thickness of one inch. The sand cushion shall be compacted by hand tamping, or as directed by the Engineer. Joints between pavers shall be a maximum of one inch and a minimum of three quarters inch in width. Joints around the edge of the pit shall be hand tight. Joints along the inner ring of blocks must be filled with a cement mortar of a wet mixture of one part Portland cement and two parts sand.

For further information, including tree pit drawings, please refer to the Tree Planting Standards prepared by the New York City Department of Parks and Recreation, from which the above tree pit standards are adapted.

Section VI - Green Infrastructure Resources

We hope that the information above has provided you with a good overview of green infrastructure, its many public and private benefits, and how green infrastructure is and will be implemented in the City of Newburgh. For further information about the topics covered in this Green Infrastructure Guide please visit the websites and documents listed below.

Green Infrastructure Generally

New York State Resources

- *2014 Draft New York State Open Space Conservation Plan* – http://www.dec.ny.gov/lands/98720.html
- *Economic Benefits of Open Space Preservation*, Office of the New York State Comptroller (March 2010)- http://www.dec.ny.gov/docs/lands_forests_pdf/openspacepres.pdf
- *Green Infrastructure Plan for Saratoga County*, Saratoga County Board of Supervisors (November 21, 2006) - http://www.saratogaplan.org/documents/FullPlan_LessApp.pdf

Other Resources

- *The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits*, Center for Neighborhood Technology and America Rivers (2010) - http://www.cnt.org/media/CNT_Value-of-Green-Infrastructure.pdf

Low Impact Development

New York State Resources

- *Better Site Design*, NYS Department of Environmental Conservation (April 2008) - http://www.dec.ny.gov/docs/water_pdf/bsdcomplete.pdf
- *Low Impact Development Design Strategies: A guide for the communities of the West-of-Hudson portion of the New York City Water Supply System Watershed*, Schoharie County Planning and Development Department (date unavailable) – (on file with CAC)
- *Local Open Space Planning Guide*, New York State Department of State (2004) – http://www.dos.ny.gov/lg/publications/Local_Open_Space_Planning_Guide.pdf
- *Town of Clinton Recommended Model Development Principles for Protection of Natural Resources in the Hudson River Estuary Watershed*, Town of Clinton et al. (June 2006) - http://www.dec.ny.gov/docs/remediation_hudson_pdf/hrewbsdclin.pdf
- *Watershed Design Guide: Best Practices for the Hudson Valley*, Orange County Planning Department and Regional Plan Association (2014) - http://waterauthority.orangecountygov.com/PROJECTS/DESIGN_GUIDE/OC-Watershed-Design-Guide_Final%20(11-24-14).pdf

Federal Resources

- *Open Space Development, Model Ordinances to Protect Local Resources*, US Environmental Protection Agency - http://water.epa.gov/polwaste/nps/openspace.cfm

Other Resources

- *Pembroke Woods: Lessons Learned in the Design and Construction of an LID Subdivision*, Michael Clar P.E. President, Ecosite, Inc. (date unknown) - http://www1.villanova.edu/content/dam/villanova/engineering/vcase/sym-presentations/2003/4A4.pdf
- *Skinny Streets and One-sided Sidewalks: A Strategy for Not Paving Paradise*, Rutgers Cooperative Extension, Water Resources Program http://www.water.rutgers.edu/Educational_Programs/Senior%20Design2008/ELC_PWP50.pdf

Green Infrastructure for Stormwater Reduction and Impact Mitigation

New York State Resources

- *City of Newburgh Green Infrastructure Feasibility Report*, eDesign Dynamics (October 2014) – [insert link when available]
- *Stormwater Management Guidance Manual for Local Officials*, NYS Department of Environmental Conservation (September 2004) - http://www.dec.ny.gov/docs/water_pdf/localall.pdf
- *New York State Stormwater Management Design Manual*, NYS Department of Environmental Conservation (Updated January 2015) - http://www.dec.ny.gov/chemical/29072.html
- *New York Standards and Specifications For Erosion and Sediment Control* (Blue Book), NYS Department of Environmental Conservation (August 2005) - http://www.dec.ny.gov/docs/water_pdf/bluebook.pdf
- *Code and Ordinance Worksheet for Development Rules in New York State, Hudson River Estuary Program*, NYS Department of Environmental Conservation (2011) - http://www.dec.ny.gov/docs/remediation_hudson_pdf/cownys.pdf
- *Barriers to Green Infrastructure in the Hudson Valley: An electronic survey of implementers*, Hudson River Estuary Program, NYS Department of Environmental Conservation and New York State Water Resource Institute at Cornell University (2012) - http://www.dec.ny.gov/docs/remediation_hudson_pdf/giresults12.pdf
- *Grant Funding Opportunities For Green Infrastructure Retrofit Projects*, Lower Hudson Coalition of Conservation Districts (October 2013) - http://www.lhccd.net/uploads/7/7/6/5/7765286/gi_retrofit_funding_opps_2013_10.pdf
- *Green Infrastructure Examples for Stormwater Management in the Hudson Valley*, Hudson River Estuary Program, NYS Department of Environmental Conservation - http://www.dec.ny.gov/lands/58930.html (This website describes a variety of green infrastructure practices, organized both by type and by county)

- *Green Infrastructure Model Local Law Project Summary Report: Process, Findings, and Implementation*, Stormwater Coalition of Albany County (November 2013) - http://www.stormwateralbanycounty.org/wp-content/uploads/2011/12/A_GrnInfModLocLawProj_SWCoalAlbCntyNY_2013_Nov_For Distribution.pdf
- *Green Infrastructure Practices at Work Video Series*, Lower Hudson Coalition of Conservation Districts - http://www.lhccd.net/green-infrastructure.html
- *Honey, It's Time to Mow the Roof: Incorporating Green Infrastructure into Municipal Planning*, Sara Jade Pesek and Sarah Kelsen, Clearwaters (Winter 2008) - http://www.nywea.org/Clearwaters/08-4-winter/06-Incorporating.pdf
- *Managing Stormwater for Urban Sustainability Using Trees and Structural Soils*, Urban Horticulture Institute, Cornell University - http://www.hort.cornell.edu/uhi/outreach/pdfs/TreesAndStructuralSoilsManual.pdf
- *Municipal Policies to Promote Green Infrastructure*, Lower Hudson Coalition of Conservation Districts (September 2012) - http://www.lhccd.net/green-infrastructure.html
- *Nyack Green Infrastructure Report*, Consensus of the Nyack Green Infrastructure Roundtable, Village of Nyack (June 24, 2013) - http://nyack-ny.gov/wp-content/uploads/2013/11/Roundtable-Report-FINAL7-1.pdf
- *Reviewing Stormwater Management in Site Design: A Guide for Planning Board Members*, Lower Hudson Coalition of Conservation Districts (2014) - http://www.lhccd.net/uploads/7/7/6/5/7765286/planning_board_sw_guide_version1_2014.pdf
- *Standards for Green Infrastructure*, New York City Department of Environmental Protection, Office of Green Infrastructure (Updated August 29, 2014) - http://www.nyc.gov/html/dep/pdf/green_infrastructure/bioswales-standard-designs.pdf
- *Stormwater to Street Trees: Engineering Urban Forests for Stormwater Management*, US Environmental Protection Agency (September 2013) - http://water.epa.gov/polwaste/green/upload/stormwater2streettrees.pdf
- *Greenstreets: Stormwater Management Portfolio*, Greenstreets Division, NYC Department of Parks & Recreation (2010) - https://www.nycgovparks.org/sub_your_park/trees_greenstreets/images/NYC_Greenstreets-Green_Infrastructure_for_Stormwater_Management.pdf
- *Woody Shrubs for Stormwater Retention Practices*, Northeast and Mid-Atlantic Regions, Ethan M. Dropkin and Nina Bassuk, Cornell University, Department of Horticulture (2014): http://www.hort.cornell.edu/uhi/outreach/pdfs/woody_shrubs_stormwater_hi_res.pdf

Federal Resources

- *Enhancing Sustainable Communities with Green Infrastructure: A Guide to Help Communities Better Manage Stormwater While Achieving Other Environmental, Public Health, Social and Economic Benefits*, US Environmental Protection Agency (October 2014) - http://www.epa.gov/smartgrowth/pdf/gi-guidebook/gi-guidebook.pdf
- *Green Infrastructure and Issues in Managing Urban Stormwater*, Congressional Research Service (March 21, 2014) - http://nationalaglawcenter.org/wp-content/uploads/assets/crs/R43131.pdf
- *Green Infrastructure Barriers and Opportunities in Camden, New Jersey*, U.S. Environmental Protection Agency (August 2013) - http://water.epa.gov/infrastructure/greeninfrastructure/upload/Camden_GI_Evaluation.pdf
- *Green Infrastructure Case Studies: Municipal Policies for Managing Stormwater with Green Infrastructure*, US Environmental Protection Agency (August 2010) - http://www.sustainablecitiesinstitute.org/Documents/SCI/Report_Guide/Guide_EPA_GICaseStudiesReduced4.pdf
- *The Economic Benefits of Green Infrastructure: A Case Study of Lancaster, PA*, US Environmental Protection Agency (February 2014) - http://water.epa.gov/infrastructure/greeninfrastructure/upload/CNT-Lancaster-Report-508.pdf
- *Implementing Stormwater Infiltration Practices at Vacant Parcels and Brownfield Sites*, US Environmental Protection Agency (July 2013) - http://water.epa.gov/infrastructure/greeninfrastructure/upload/brownfield_infiltration_decision_tool.pdf

Other Resources

- *City of Philadelphia Green Streets Design Manual*, Mayor's Office of Transportation and Utilities (2014) - http://www.phillywatersheds.org/img/GSDM/GSDM_FINAL_20140211.pdf
- *Green Infrastructure: A Landscape Approach*, American Planning Association, Planning Advisory Service, Report Number 571 (January 2013) - https://www.planning.org/pas/reports/subscriber/archive/pdf/PAS_571.pdf
- *Green Infrastructure and the Law*, Planning & Environmental Law: Issues and decisions that impact the built and natural environments, Karen M. Hansen (July 12, 2013) - http://dx.doi.org/10.1080/15480755.2013.824791
- *Green Infrastructure Standards*, District of Columbia, Department of Transportation (2014) - http://ddot.dc.gov/sites/default/files/dc/sites/ddot/publication/attachments/2014-0421-DDOT%20Green%20Infrastructure%20Standards.pdf

- *Nine Ways to Make Green Infrastructure Work for Towns and Cities*, Regional Plan Association (November 2012) - http://www.rpa.org/library/pdf/RPA-9-Ways-to-Make-Green-Infrastructure-Work.pdf
- *Regional and Municipal Stormwater Management: A Comprehensive Approach*, Emmett Environmental Law & Policy Clinic and the Environmental Policy Initiative, Harvard Law School (June 2014) - http://blogs.law.harvard.edu/environmentallawprogram/files/2014/07/Regional-Stormwater-paper_FINAL-6-19-14.pdf
- *Sustainable Urban Infrastructure: Policies and Guidelines Vol. 1*, Chicago Department of Transportation (July 2013) - http://www.cityofchicago.org/content/dam/city/depts/cdot/Sustainable%20Transportation/SUIGv1.pdf

Green Infrastructure for Urban Air Quality

New York State Resources

- *A Municipal Official's Guide to Forestry in New York State*, New York Planning Federation, NYS Department of Environmental Conservation and Empire State Forest Products Association (2005) - http://www.dec.ny.gov/docs/lands_forests_pdf/guidetoforestry.pdf
- *Tree Planting Standards*, New York City Department of Parks and Recreation (February 2014) - https://www.nycgovparks.org/pagefiles/53/Tree-Planting-Standards.pdf

Federal Resources

- *Sustaining America's Urban Trees and Forests*, General Technical Report NRS-62, US Forest Service (June 2010) - http://www.fs.fed.us/openspace/fote/reports/nrs-62_sustaining_americas_urban.pdf

Other Resources

- *Adapting to Urban Heat: A Tool Kit for Local Governments*, Georgetown Climate Center (August 2012) - http://www.law.georgetown.edu/academics/academic-programs/clinical-programs/our-clinics/HIP/upload/Urban-Heat-Toolkit_RD2.pdf
- *Trees in Urban Design*, Paul Crabtree and Lysistrata Hall, Congress for New Urbanism (date unknown) - http://www.cnu.org/sites/www.cnu.org/files/trees_in_urban_design.pdf
- *The Value of Green Infrastructure for Urban Climate Adaptation*, The Center for Clean Air Policy (February 2011) - http://ccap.org/assets/The-Value-of-Green-Infrastructure-for-Urban-Climate-Adaptation_CCAP-Feb-2011.pdf

Development of Regional Unit Hydrograph Parameters for Application to Ungaged NYS Watersheds

Basic Information

Title:	Development of Regional Unit Hydrograph Parameters for Application to Ungaged NYS Watersheds
Project Number:	2014NY212B
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End Date:	12/31/2015
Funding Source:	104B
Congressional District:	20
Research Category:	Climate and Hydrologic Processes
Focus Category:	Surface Water, Methods, Hydrology
Descriptors:	None
Principal Investigators:	James E. Kilduff

Publications

There are no publications.

Development of Regional Unit Hydrographs for Application to Ungaged Watersheds in New York

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ABSTRACT

In this research, we developed regional regression equations for estimating Clark's hydrograph parameters, using geomorphological watershed characteristics as input data. It was possible to model both the Storage Coefficient (R) and Time of Concentration (T_c) with a coefficient of correlation of 0.99 and 0.90 respectively. In addition, SCS hydrograph parameters were calculated for comparison purposes. As expected, the SCS hydrographs overestimated the peak flow of rainfall-runoff events, and the Clark's hydrograph shows a fit better the observed hydrograph for the watersheds studied.

ACRONYMS & ABBREVIATIONS

AIC – Akaike's Information Criterion

CN – Curve Number

ERH – Effective Rainfall Hyetograph

in - inches

IUH – Instantaneous Unit Hydrograph

GIS – Geological Information Systems

NCDC – National Climate Data Center

NYSDEC – New York State Department of Environmental Conservation

R – Storage Coefficient from Clark Hydrograph

RH – Direct Unit Hydrograph

RMSE – Root Mean Square Error

SCS – Soil Conservation Service

T_c – Time of Concentration parameter from Clark hydrograph

UH – Unit Hydrograph

USGS – United States Geological Survey

1. STUDY AREA

This study focused on the New York counties of Saratoga, Montgomery, Otsego, Schoharie, Albany, Rensselaer, Delaware, Greene, Columbia, Sullivan, Ulster, Dutchess, Orange, Putman, Rockland and Westchester County (Figure 1). The northern-most latitude was in Saratoga County, while the southern-most was in Westchester County. The eastern-most longitude was in Rensselaer County, whereas the western-most longitude was in Delaware County.

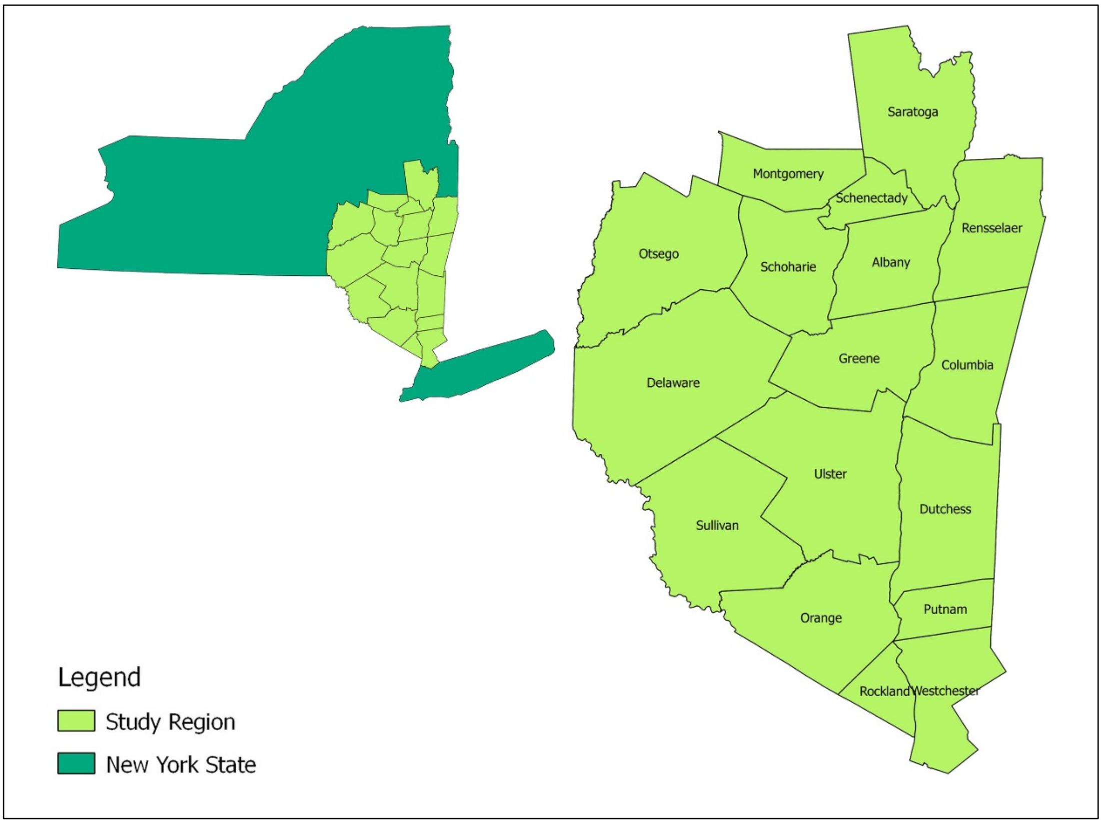

Figure 1: New York State counties included in the study region.

2. DATA SOURCES AND STREAMGAGE SCREENING

United States Geological Survey (USGS) stream gage data are available on the USGS website as a shapefile. The following criteria were used to select stream gage data. To assure that land use patterns were current, we chose data from between 01/01/2003 and 12/31/2013. Data for unregulated rivers were selected to avoid the need to route flows through controls such as dams and impoundments. We selected drainage areas between 1.5 and 80 square miles, having a maximum urban land use of 5%. Finally, the gaging stations were generally within 25 km from the nearest 15-min rain gauge to assure the accuracy of rainfall data.

The dam locations and the hydrograph network information was downloaded from NYSDEC information database (Google Earth: Environmental Maps) and USGS information database (USGS TNM 2.0 Viewer), respectively.

From the ten-year time span from 01/01/2003 to12/31/2013, six storm events were suitable for analysis. Streamflow data was downloaded from the USGS instantaneous data archive (USGS Instantaneous Data Archive - IDA) and USGS current condition for streamflows database for New York State (USGS Current Conditions for New York Streamflow). Precipitation datasets were downloaded from National Climate Data Center database (NCDC) (Maps | NCDC - National Climatic Data Center).

3. INSTANTANEOUS UNIT HYDROGRAPH

A unit hydrograph (UH) is the hydrograph of direct runoff resulting from one unit of rainfall excess over a watershed for a determined duration. They are often named after the duration of rainfall excess. Thus, the UH for a storm having three hours of rainfall excess referred to as a 3-hr unit hydrograph. Unit hydrographs having the same duration of precipitation excess can be used for storms having different intensity. However, multiple unit hydrographs may be necessary to model different rainfall excess durations. The limitations intrinsic to UH's are overcome by using the Instantaneous Unit Hydrograph (IUH). An IUH is the hydrograph of direct runoff resulting from instantaneous rainfall excess volume of one unit (Patra, 2008).

Among the various IUH methods are the Snyder and Clark approaches, which are currently the two most widely used for synthetic unit hydrograph creation in hydrologic modeling (Jena and Tiwari, 2006; Chu and Steinman, 2009; Wilkerson and Merwade, 2010; Halwatura and Najim, 2013; Straub et al, 2000). To determine the most appropriate method, each was used to fit data for three different events in three different watersheds located in the study region. The two methods were similar; however, the Clark approach performed somewhat better overall, and is commonly used for the development of regression equations for estimating synthetic hydrograph parameters based on geomorphological characteristics in the United States (Wilkerson and Merwade, 2010; Straub at al, 2000; Melching and Marquardt, 1996). For these reasons, Clark's Instantaneous Unit Hydrograph (Clark, 1945) was used in this study.

Clark's approach for estimating the unit hydrograph for a watershed is based on the effects of translation and attenuation in the movement of flow in a watershed. Translation is the movement of waves from one point upstream to another downstream; it does not depend on the magnitude of the storm. Attenuation is the reduction in the flow rate mainly due to the storage capacity of the channel, which is an index of the temporary storage of precipitation excess in the watershed as it drains to the outlet point (U.S. Army of Corps of Engineers, 2000).

Translation of flow through a watershed is represented by a time-area concentration curve bounded by time of concentration (T_c) – or channel travel time (Clark, 1949) and expresses "the curve of the fraction of watershed area contributing runoff to the outlet of the watershed as a function of time since the start of effective precipitation" (Melching and Marquardt, 1996). Melching and Marquardt (1996) assert that the actual time-area curve for the watershed need not be determined to obtain a reasonable unit hydrograph. In fact, HEC-HMS utilizes a dimensionless time-area curve built into the software to represent this temporal distribution of watershed area contributing to the runoff at the outlet of the watershed (U.S. Army Corps of Engineers, 2000) and in most instances, this approach is satisfactory for obtaining a reliable synthetic unit hydrograph (Melching and Marquardt, 1996). It is important to note that the time of concentration for the Clark hydrograph has different definitions than the traditional ones used in hydrograph analysis. In the typical definition, time of concentration is the time from the end of excess rainfall to the inflection point where the recession curve begins (National Engineering Handbook, 2010). The inflection point is defined as the time when overland flow to the channel network ceases; beyond that, the measure runoff results from drainage of channel storage (Melching and Marquardt, 1996). Clark's T_c is the time between cessation of runoff and the inflection point, thus representing the time required for the last drop of effective rainfall at the hydraulically most distant point in the watershed to reach the channel outlet.

Attenuation of flow is represented by a linear reservoir, for which storage is related to the outflow as $S = RO$, where S is the watershed storage, R is the storage coefficient, and O is the outflow from the watershed.

Parameters for the SCS Hydrograph were also optimized to provide insight on how the SCS approach compares to the Clark approach. For the method of hydrograph synthesis employed by the Soil Conservation Service (SCS), the general hydrograph is scaled by the time lag to produce the unit hydrograph (U.S. Army Corps of Engineers, 2013). Therefore, the lag time is the only input parameter needed to generate the hydrograph. HEC-HMS allows the user to model using two different graph types, Standard and Delmarva shape. The Standard shape is more widely applicable across the United States (U.S. Army Corps of Engineers, 2013). The definition of time lag for the SCS unit hydrograph follows the traditional definition, as the time from the center of mass of rainfall excess to the peak of the hydrograph (Bedient et al, 2008). For the initial value in the optimization process, time lag was estimated according to the above definition. The same method was used for precipitation abstraction, independent of the unit hydrograph approach.

GEOMORPHOLOGIC INSTANTANEOUS UNIT HYDROGRAPH

Geomorphological characteristic used in our regression analysis were obtained from the StreamStats application for the state of New York ("New York: The StreamStats Program", n.d.). In addition to the characteristics readily available from StreamStats, two other characteristics were included – basin perimeter and circulatory ratio. The first is easily determined with GIS tools and the second was determined from other parameters defined in Table 1.

Table 1: Geomorphological parameters

Parameters, Symbol	Definition
Drainage area, A_d	Area that drains to a point (streamgage station) on a stream in square miles.
Basin Perimeter, P_b	Basin perimeter, in miles, measured along entire drainage-basin divide.
Main channel length, L_c	Main channel stream length in miles
Channel Slope, S_c	Main channel 10-95 slope (the difference in elevation between points 10 percent and 85 percent of the distance along main stream channel, in feet per miles.
Basin Slope, S_b	Average basin slope in feet per mile.
Slope Ratio, S_r	Ratio of main channel slope to basin slope.
Basin Lag Factor, L_f	Basin Lag factor defined as $L_c\,/\,\sqrt{(sl_{up}+1)*(sl_{lo}+1)}$
Basin storage, b_s	Percentage of total drainage area shown as lakes, ponds and swamps.
Urban land use percentage (1992), L_u	Urban land use percentage (1992) within the watershed.
Forest coverage percentage, F_c	Percentage of area coverage by forest.
Circulatory Ratio, R_c	A dimensionless parameter defined as the ratio of the basin area, A_d to the area A_p of a circle having a circumference equal to the basin perimeter, P_b . $R_c = \frac{A_d}{A_p}$, where $A_p = \frac{P^2}{4\pi}$, p = perimeter.

Notes: sl_{up} and sl_{lo}: 10-85 slope of, respectively, upper and lower half of main channel.

RAINFALL-RUNOFF EVENT SELECTION

Selection of storm events were done in an attempt to conform to the unit hydrograph concepts, that is, the volume of direct runoff resulted from a storm uniformly distributed over the drainage area is equal to the excess precipitation of that given storm. Viessman (1977, p. 117) recommends that storms selected for deriving unit hydrographs meet three main characteristics:

1. Simple storm structure, that is, storm with well-defined distinct peaks;
2. Uniform distribution of excess rainfall throughout the period;
3. Uniform spatial distribution over the entire watershed.

When calibrating synthetic unit hydrographs in HEC-HMS, importance of the second characteristic is reduced when the first one is satisfied. This is because multiple periods of effective precipitation are adequately deconvoluted in the calibration process if the DRH is well defined with distinct peaks (Straub et al., 2000). In addition to these three main characteristics, Viessman (1977) also recommends that the excess rainfall from selected storms should range from 0.5 to 1.75 in. Straub et al. (2000) justifies this range by asserting that the design of storms simulated with a synthetic unit hydrograph will result in direct runoff in this range. For some watersheds, optimized parameters for events having runoff less than 0.4 in could significantly differ from those optimized for events having greater runoff. Further, selection of storms resulting in at least 0.4 in of direct runoff are likely to reduce problems resulting from non-uniform spatial distributions of effective precipitation (Melching and Marquardt, 1996). That is because larger storms tend to reduce the effects of areal variability of runoff, partial-area runoff, and large differences in the time distribution of effective precipitation resulting from small errors in the applied abstraction model (Laurenson and Mein 1985, Melching and Marquardt, 1996). Therefore, to satisfy these conditions and decrease the possibility of events affected by snowmelt, a preliminary screening of suitable storms should meet the following criteria before further analysis:

1. Storm event occurring from March to December with no or few precipitation three days previous to the storm and 24 hours after the storm;
2. No precipitation gap 1 hour before and after storm record;
3. Runoff ranging from 0.4 to 1.75 in.

To assure the best suitable storms were selected, a list of all the possible events was made and their hydrographs were generated. The best six storms with well-defined single peaks were selected for optimization; the final Tc and R parameters represent the average of the successful optimizations. Functions in R language were coded to aid in the analysis (see Appendix C). The above criteria for hydrograph selection was aimed to filter the highest streamflows with consistent antecedent moisture conditions facilitating the baseflow separation with accuracy.

BASE FLOW SEPARATION

Recorded streamflows hydrographs represent the sum of runoff flow and baseflow, which is the contribution from aquifers into the streams. Therefore, baseflow must be removed from the total streamflow hydrograph before modeling surface runoff. Several procedures are available to separate baseflow. In the field, and a common practice by engineers involves the visual inspection of the hydrograph, and a simple graphical construction where a straight line is drawn between the start of the rising limb and the end of the recession limb of the hydrograph (Patra, 2008). Patra (2008) also describes other graphical techniques. Although these methods are easy to apply, the are subjective and time consuming if the model contains a large number of hydrographs.

A less subjective approach to separate baseflow involves Recursive Digital Filters (RDF) as described by Li at al. (2014). In the frequency spectrum of hydrographs, long waves are more likely to be associated with baseflow due to the smoothing in the streamflow hydrograph that is caused by the discharge of groundwater into the streamflow, while the high frequency variability of the streamflow will primarily be caused by direct runoff (Eckhardt, 2005). Therefore, it should be possible to separate the baseflow by filtering out low-frequency changes from the higher frequencies in the streamflow hydrograph (Nathan and McMahon, 1990).

The most commonly filtered techniques in literature are those presented by Eckhardt (2005) and Lyne and Hollick (1979). Both filters are considered one parameter filters and the Eckhardt (2005) filter takes into account the baseflow recession constant. These filters have been reviewed and compared in several studies (e.g. Arnold et al., 1995; Nathan and McMahon, 1990; Eckhardt, 2008; Chapman, 1999); although it was found that the LI filter technique is comparable in accuracy in predicting the manually separated baseflow (Arnold et al., 1995 and Nathan and McMahon, 1990) and that the Eckhardt filter is hydrologically plausible (Eckhardt, 2008), those studies were based on subjective measure, such as plausibility of hydrological behavior (Li at al., 2014). In a new paper, Li at al. (2014) compared all three filters techniques with baseflow data obtained from physical models and their work used to base the choice of the LI filter algorithm for this study.

Li at al. (2014) tested the performance of Lyne and Hollick (LH), Boughton, and Eckhardt filters by comparing the baseflow hydrograph derived from the RDFs and those obtained from a fully integrated surface water/groundwater (SW/GW) models. The filters were analyzed for a synthetic catchment with 66 combinations of different catchment characteristics and hydrologic inputs. They found that the LH filter better matches the SW/GW model having a good performance for 77.3% of the trials. Li at al. (2014), also reports that the Boughton and Eckhardt filters are not able to match both the time and magnitude of the baseflow hydrograph simulated by SW/GW model, for catchment with small baseflow contribution. However, still according to Li at al. (2014), this problem does not appear to exist with the LH filter.

Any filter requires one or more parameters as input and although the filter technique is considered an objective approach, it is not the same with the selection of its filter parameter remaining an open question (Ladson at al., 2013). Nathan and McMahon suggest that the parameters falls in the range of 0.9 to 0.95; however, Li at al. (2014) found a considerable difference between the minimum and maximum optimal filter parameter values suggesting that the use of one parameter is inappropriate and the optimal parameter is dependent on the watershed characteristics and hydrological inputs.

The filter can be passed on the streamflow data several time, following the sequence forward-backward-forward. The number of passes depends on the time step of the flow values. According to Ladson at al. (2013), three passes, of the LH filter are commonly used in daily datasets. Hill et al., 2013 calibrated the filter factor and number of passes for daily time step for a series of 10 catchments to best match the graphical approach as reviewed by Brodie and Hosteler (2005); they found the number of passes to fall in the range of 3 to 9 passes.

For this work, the number of passes and filter parameter were calibrated to as such, that the end point of surface runoff (the point at which the baseflow filter rejoins the streamflow curve) would match the time in which a plot of log of flow against time changes direction, for it represents the beginning of the baseflow recession segment as reviewed in standard books (Patra, 2008). It was found that for our 15 minutes time step dataset, passing the filter more than once overestimated the end of surface runoff by usually more than 10 hours, therefore 1 pass was adopted.

Overall, the RDF technique might be considered just as arbitrary as separation baseflow based on series of straight lines. However, this technique has the advantage of providing objective and repeatable estimate of baseflow that is easily automated (Nathan and McMahon, 1990), reducing the time for analysis of streamflow records.

PRECIPITATION LOSS METHOD

For modeling unit hydrographs, it is necessary to know the excess of precipitation causing the observed runoff. Thus, the subtraction of runoff from the total precipitation yields the precipitation loss. However, the issue is to know how this total loss is distributed along the precipitation event. There are twelve precipitation loss methods implemented in HEC-HMS. This includes the two most widely used, the initial and constant loss method and the SCS curve number (CN) method. The SCS CN approach estimates precipitation excess as a function of cumulative precipitation, soil cover, land use, and antecedent moisture and therefore, the precipitation loss decreases along the precipitation event. All of these characteristics are embodied in the CN parameter. On the other hand, the initial and constant method is simpler assuming the losses are constant throughout the storm.

Halwatura and Najim, (2013) tested the performance of SCS curve number and initial and constant method for event and continuous hydrologic modeling using both the Clark and Snyder transformation methods, for the Attanagalu Oya (river) catchment in Sri Lanka. They found the SCS curve number did not perform well. According to the authors, the CN method seems to work the best in agricultural watersheds, mediocre for rangelands and poorly for forested watersheds (Halwatura and Najim, 2013).

For the present study it was tested the performance of both method for three different watershed including three different events for each watershed. The initial and constant method was found to yield better results and therefore was chosen as the precipitation loss method.

PARAMETER OPTIMIZATION

In the mathematical optimization processes, objective function is defined as the target function to be minimized or maximized. These functions are an index of the difference between the simulated and observed values. Eight objective functions are available in HEC-HMS for calibrating parameters. Minimizing the root mean square error (RMSE) was found to yield better results; therefore, this function is used to calibrate the Clark Synthetic Unit Hydrograph parameters:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

where y_i is the observed values, $\hat{y}_i$ the estimated value and n the number of observed values.

Initial values were estimated as a start point for the search of the best (optimal) parameter values. As in any search for the best parameters for a given function, the initial values influences in the result of the optimized parameters: as close the initial values are to the actual parameters as quicker the search is and more accurate the result will be. Therefore as an attempt for a good initial estimate, t_c was estimated as being the traditional time of concentration using Kirpich equation (Patra, 2008):

$$t_c = 0.000323L^{0.77}S^{-0.385}$$

where t_c is the time of concentration in hours, L is the length of the longest streamflow in the watershed (m), and S the slope of the channel, in this study, the 10-85 slope is used; and the storage coefficient (R) was estimated as a ratio of R and t_c:

$$\frac{R}{t_c + R} = 0.6$$

The value of 0.6 is analogous to those used by Wilkerson and Merwade (2010). The priority of optimization was to match the peak flow rate, time to peak, total runoff and overall hydrograph shape. An optimization was considered successful when an estimated peak flow would fall within 5% of observed; time to peak within 15 minutes of observed and total runoff within 12% of observed which at the most of the optimizations it guarantees a good fit of the overall optimized hydrograph to the observed hydrograph. The estimated initial values were not used for further analysis but just as a starting point for the optimization process.

REGRESSION EQUATION DEVELOPMENT

General approach

Multiple regression is the most common method used in hydrological applications, especially for transferring information from gaged to ungaged sites (Avdulla and Lettenmaier, 1997). In this study, a multiple regression model is used in an attempt to derive the whole shape of Clark's hydrograph for ungaged sites based on streamflow information collected from 12 gaged sites. Therefore, this is an attempt to explain the variation in streamflow, the dependent variable, through the geomorphological characteristics of the watershed, the independent variable, using linear model.

This relationship between dependent and independent variable is written as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_p X_p + \varepsilon ,$$

where Y is the dependent or response variable (Clark's UH parameters), $X_1, X_2, \dots, X_p$, are independent variables (geomorphologic attributes), also called explanatory variables, $\beta_0, \beta_1, \dots, \beta_p$, unknown coefficients and ε the error in the function or the part of the response in Y that cannot be explained by the independent variable. The least squares method is used to estimate the unknown coefficients:

$$\beta = (X'X)^{-1}X'Y,$$

where β is a p x 1 vector containing the estimated values of $\beta_0, \beta_1, \ldots, \beta_p$, p = 1,2,3,…n, p = number of independent variables, X is a p x 2 matrix containing $X_1, X_2, \ldots, X_k$ with 1's vector in the first column and Y is a i x 1 vector containing Y_i, i = 1,2,3…n, n = length of the sample. Detailed explanations of the mathematical processes of least square method are provided by Draper and Smith, (1981).

Initially we attempted to fit the model with all variables (without any transformation of the variables) that explain the variance in the Clark's parameters. Stepwise procedure was then employed to select the best number of variable. The procedure was applied in order to avoid insignificant variable in the model, thus explaining as much of the variance of Y as possible with small number of independent variable; the fitted model is then diagnosed and if necessary, another model with transformed variables is attempted, following the same procedure, until a satisfactory equation is modeled.

Stepwise procedure is a method for adding or deleting variables from the model and calculating the performance of the equation at each step. It can be performed by going forward, backward or both through the process. If backwards, the model starts with the maximum number of variables and then one variable is deleted from regression at a time. The process continues until there is no variable to be deleted or certain criteria is met. If forward, the process follows the same steps but adding variables rather than deleting. Statistics of the model is calculated and the model with the best statistic is the final selected model. MASS package (Venables and Ripley, 2002) in R (R Core Team, 2014) is utilized in the stepwise procedure.

It is important to note, that this procedure does not necessarily test all possible combination of variables and therefore it does not return the best set of variable to be included in the model but returns an acceptable one. Akaike's Information Criterion (AIC) is used as the statistic test.

The model returned with the stepwise procedure, is reduced by taking out all the variables that are not significant to the regression model, based on the AIC statisticthus producing a third model. The null and alternative hypothesis are respectively described as:

$$H_0: \beta_p = 0 \qquad H_1: \beta_p \neq 0$$

Where H_0 and H_1 are respectively the null and alternative hypothesis and β_p is the coefficient for the pth variable. Under normality assumption, an appropriate test statistic for testing this null hypothesis is the t-test (Chatterjee et al, 2000). Thus, the null hypothesis is rejected when $P_r (> | t_k |) \leq \alpha$. Meaning the situation can be described as such:

- The predictor is significant in the current model if the probability that a random variable having a student t distribution with n-p-1 degrees of freedom is greater than the absolute value of t_k,
- The predictor is less than the significance level α, which for this study is 0.05, where t_k is the observed t-test for the k_{th} variable, otherwise the variable is insignificant and therefore taken out of the model.

The explanatory variables or the geomorphological characteristics in this case to be used in the modeling process were determined by plotting the dataset (average of optimized parameters for each streamgage stations and watershed geomorphology associated with the station) in a scatterplot to assess whether a specific geomorphological parameter has any correlation with Clark's UH parameters, for the study region. All variable that showed at least minimal correlation were tested in the model.

Regression Diagnostics

Residuals: In performing regression analysis, some assumptions about the residuals are made: they are independent and normally distributed, have zero mean and a constant variance, σ^2 (Draper and Smith, 1981). In a correct fitted model, the residuals should exhibit tendencies that do not deny these assumptions. Normality of residual is validated by the examination of a normal probability plot of the standardized residuals. The plot should assemble a straight line with intercept of 0 and slope of 1 (Chatterjee et al, 2000); constant variance is evaluated by plotting the residual against $\hat{Y}_i$; independence of residual is evaluating by plotting the residuals against the explanatory variables X_{j1}, $X_{j2}, \ldots X_{jk}$,, which is expected to have an overall impression of a horizontal band of residuals.

If the modeled regression fails to meet the criteria above, transformation of variables will be employed to achieve the requirements. Transformation on dependent variable is performed with the Box-Cox method. It is a procedure to identify the best exponent for a power transformation. Two different transformation family is tested, Box-Cox and Yeo and Johnson family, to find the better exponent. Car package (Fox and Weisberg, 2011) is applied for power transformation analysis.

M*ulti-collinearity:* Collinearity in regression analysis happens when two or more variables are dependent of each other. The assumption that the explanatory variables are linearly independent of each other plays an important role in the estimation of the parameter using the least square solution, for this assumption is needed to guarantee the uniqueness of the least squares solution. In addition, presence of multi-collinearity may result in other undesirable consequences. Helsel and Hirsch, (1992) point out that, equations might have unrealistic slope coefficients even though being acceptable in terms of F-tests. Multi-collinearity was diagnosed using the variance inflation factor (VIF) presented by Marquardt (1970).

$$VIF_j = 1/(1 - R_j{}^2)$$

Where VIF_j is the VIF for variable j, R_j^2 is the R^2 from a regression of the jth explanatory variable on all of the other explanatory variables. $VIF_j > 10$ indicate serious problem of multi-collinearity.

RESULTS

Stream gage Selection

A total of 18 streamgage (Table 1 in Appendix A) and 6 rain gauge (Table 2) located at the study region, were found to meet the criteria as defined at methodology. The streamgages distances from the closest rain gauge vary from 0.8 to 23.9 km. The exception is the station 01330000 that although it is located closer (29 km) to other rain gauge, rain gauge 308586 was preferred over 307549 because mostly of the drainage area is closest to the last.; 44% of the streamgages is located on the county of Ulster.

From the total useful streamgages, 14 were used to develop the regression equation and four (013621955, 01349810, 01363382 and 01434017) were used to verify the model. The stations selected to develop the regression equations were chosen based on the following criteria: a drainage area varying from 1.95 to 76.85 square miles, urban land use varying from 0 to 3.32 percent (although 85% of the drainage areas has an urban land use below 0.6%), basin storage (storage in form of lakes, ponds and swamps) varying from 0 to 7.35%, with 70% of the station having basin storage below 1%, and forest cover varying from 37.1 to 100%, with the most of the watersheds having above 98% of total percentage area covered by forest.

Table 2: Rain gauge station number and used time span (mm/dd/yyyy).

Station number	Used time span
302454	05/01/2003 – 05/01/2013
305435	05/01/2003 – 05/01/2013
302953	05/01/2003 – 05/01/2013
301521	05/01/2003 – 12/01/2010
308586	05/01/2003 – 03/01/2013
308406	05/01/2003 – 05/01/2013

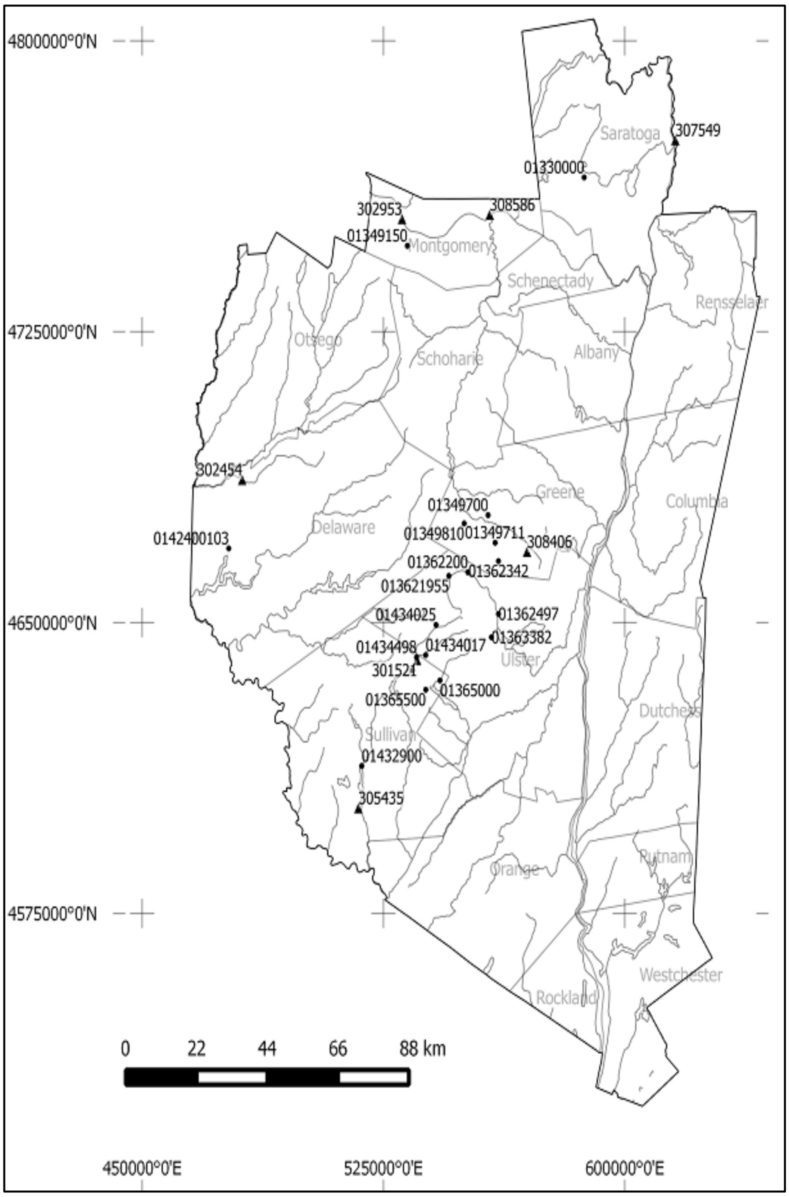

Figure 2: Streamgage stations, watershed boundaries, rain gauges used in the study. Note: Station 307549 was not used, but was put on the map to illustrate the point discussed in text. Triangles are rain gauges, circles are stream gauges.

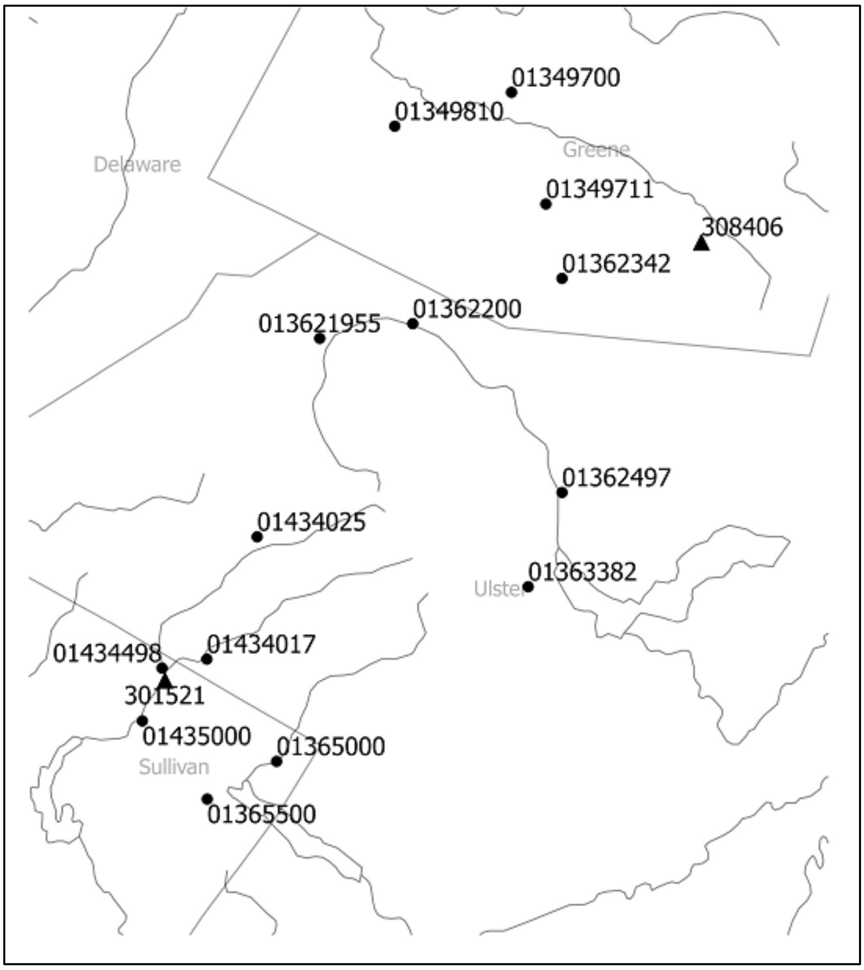

Figure 3: *Detail of F*igure 2. Triangles are rain gauges, circles are stream gauges. Map not *to* scale.

Events selection and parameter optimization

Seventy-six rainfall-runoff events from 14 watersheds were selected for the optimization process (see table 1 in appendix A). HEC-HMS models for the watersheds were set and the data uploaded into the software. During the optimization, it was noticed as expected, that peak flow is more sensible to R values, making the flow greater to smaller R, and the time of peak was more sensible to Tc values, increasing as Tc values increase. It was also noticed that the time and effort to optimize the parameter, proportionally increased with the increase in the distance from the closest precipitation station. It is suggested that, because of the spatial variation of rainfall/rainfall intensity, data collected from those station do not accurately depict the precipitation events within the watershed. Still, those data are the best 15 min record precipitation data available in the study.

From the total events, 41 had Clark Unit hydrograph parameters successfully optimized. Except by station 142400103, it was successfully possible to optimize at least two event for each station; stations 01434025 and 01365500 failed the optimization for the six events and therefore were not considered for equations development.

SCS hydrograph

Six events from four different stations were optimized following the methodology applied to the previous discussed sections. The objective of the optimization of SCS parameter is to verify the hypothesis that the SCS overestimate peak flows. As expected and shown on the hydrographs on appendix B.2, SCS method overestimated by over 23% the peak flow for the great majority of the events optimized, while for the same events using Clark's transformation method, the error of the estimated hydrograph is never more than 5%.

Regression Equations Development

Initially it was attempted to include in the model as many variable as possible, so we could evaluate their significance, and after running the stepwise procedure and taking out variable that do not meet the criteria of 5% of significance, get the modeled equation. Therefore, all variables were initially included in the model, except the basin slope that seemed to have the weakest correlation. After following the steps defined at in the methodology, the first model comprises of nine variables:

$$Tc = 26.73 + 0.042Sc + 0.247Lc - 14.709Lf + 1.41Lu - 0.214Fc + 0.041Ad - 64.308Sr - 20.341Rc$$

Although this model predicts well T_c for the data range used, having Adjusted R Squared of 0.9978, the residual is not normally distributed and therefore invalidates the standard tests of significance since they are based on the normality assumptions (Chatterjee et al, 2000). Transformation in the dependent variable was attempted to normalize the residual.

A visual inspection of the scatter plots of geomorphological characteristics against the time of concentration (figure 1 in appendix B) shows that the relationship is not linear for any of those geomorphological characteristics. It is also noticed the presence of outliers. Which can significantly change the coefficients of the model. Take for instance, the point 1.9 and 12.2 for x and y axis respectively, where this outlier point is changing the slope of the smooth trend line.

Watersheds 01330000 and 01362342 appeared to have uncommon behavior (figure 1 in appendix B), when plotted the time of concentration against the watershed characteristics, significantly changing the trend line for those relationships in some cases. From an inspection on the data for basin 01362342, it is found a significant difference in the optimization of one event to the other two (see table 1 appendix A). Since only successful optimizations were included in the regression model and steps with double verifications were thoroughly taken throughout the study it is believed the differences to not be errors on data or on the optimization process but measurements might be being influenced by other parameters not considered or verified on the study. As for Basin 01330000, no explanation its behavior was found through the inspection of the data and results from this station. However due to the failures on trying to fit the data to several different linear model, these two stations were taken out from the regression process. The final regression model for T_c:

$$Tc^{1.5} = -9.868 + 1.845\ln(S_c) + 10.23\sqrt{L_u} + 6.866x10^{-5}{A_d}^{2.5} + 7.772x10^{-3}{R_c}^{-4.47},$$

is the result of the transformation on response variable to achieve normality of residuals and on the predictors to achieve linearity. All the variables are significant on a significant level of 5% (table 3).

Table 3: t-statistc test for estimated coefficients.

Variable	**Pr(>|t|)**
Intercept	0.006932
Channel slope $\ln(S_c)$	0.009165
Urban land use (L_u)	0.000204
Drainage area (A_d)	0.047994
Circulatory ratio (R_c)	0.004617

The unadjusted and adjusted R^2 statistic for the model are 0.9903 and 0.9825, respectively. It is important to note that from the Q-Q normal plot (Figure 4 in Appendix B), it can be inferred that the residuals do not follow a perfect normal distribution, which lessens the precision of the statistics tests of significance. Yet the result of the residual distribution as depicted in Figure 4 is the closest to a normal distribution as attained by the response transformation. Overall, the model predicts the time of concentration for watersheds used to develop the equation well. Further analysis on the power of model to predict data not used for regressing T_c will be discussed later. Analysis of multi-collinearity does not indicate multi-collinearity on the model (Table 4).

Table 4: Multi-collinearity results for final Tc model.

Variable	**VIF**
Channel slope $\ln(S_c)$	0.1.81
Urban land use (L_u)	3.29
Drainage area (A_d)	2.5
Circulatory ratio (R_c)	1.98

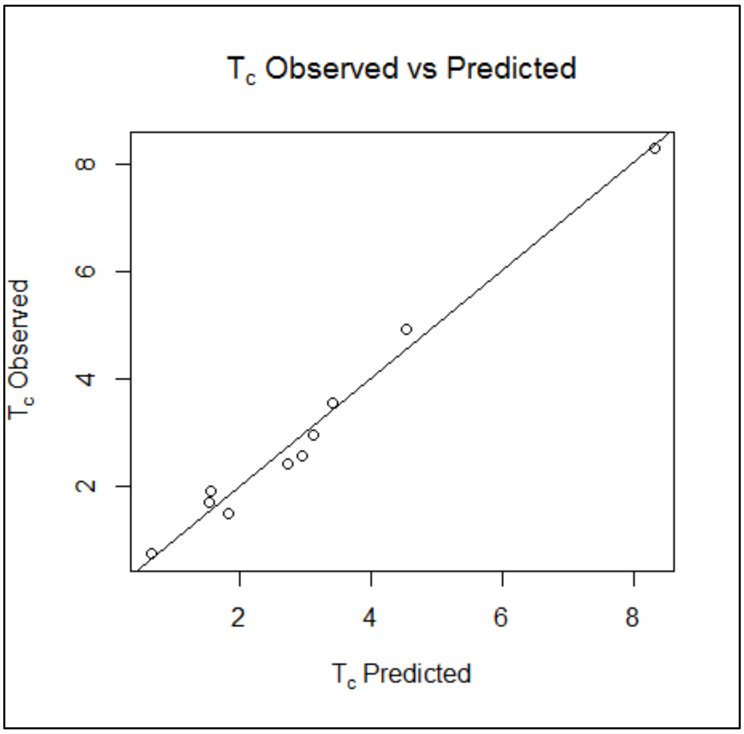

Figure 4: Observed versus predicted Tc.

Wilkerson and Merwade, (2010) modeled regression equations to estimate parameter of *R* and T_c for Clark's IUH using two different datasets of geomorphologic parameters, one with 29 variable obtained from GIS computational tools and other with 10 parameters obtained from the Stream Stats application. The objective of using two different dataset was to evaluate a simpler (with fewer parameters) would perform similarly as models with 29 parameters. The results show that the performance of equations modeled using only parameters available at Stream Stats application are significantly inferior then the all-parameters model.

Storage Constant: *R*

The same steps applied to the regressional development of T_c were applied to the development of *R*. An initial visual inspection of the scatterplots (Appendix B) shows that not many variables explain the variance in *R*. Obtaining a model without any transformation was an unsuccessful. After trials including transformation on the predictors (transformation to achieve linearity), a final equation including five predictors were regressed:

$$R = -9.506 + 0.8b_s + 0.491\sqrt{S_b} - 0.064Fc + 0.194\frac{1}{S_r} + 0.056P_b ,$$

The R^2 and adjusted R^2 for the above equation are 0.9066 and 0.8288, respectively. In an attempt to simplify the model, insignificant variables were taken out if they were within a significant level of 5%. According to results showed in Table 5, showing the *t*-statistic test for each variable, the regressors forest and basin perimeter should be taken out. However, the explanation power (attained significance) for the basin storage variable, showed to be dependent of forest and basin perimeter variables together. Therefore, in order to take these two variables out of the model, it should be necessary to take out the basin storage variable, which would significantly decrease the performance of the model, dropping to 0.638. Therefore, it was preferred, for this case, to reduce the significance level to 10% thus, including all variables from above equation.

Table 5: Significance test of predictors for *R* regression model

Predictor	**$P_r(>\|t\|)$**
Basin Storage	0.01927
Basin Slope	0.01555
Forest Coverage	0.05780
Slope Ratio	0.00203
Basin Perimeter	0.06376

Graphs on Appendix B (Figure 5) show normality of residuals validating the significance tests based on normality assumptions. Figure 5 depicts the fit of the model.

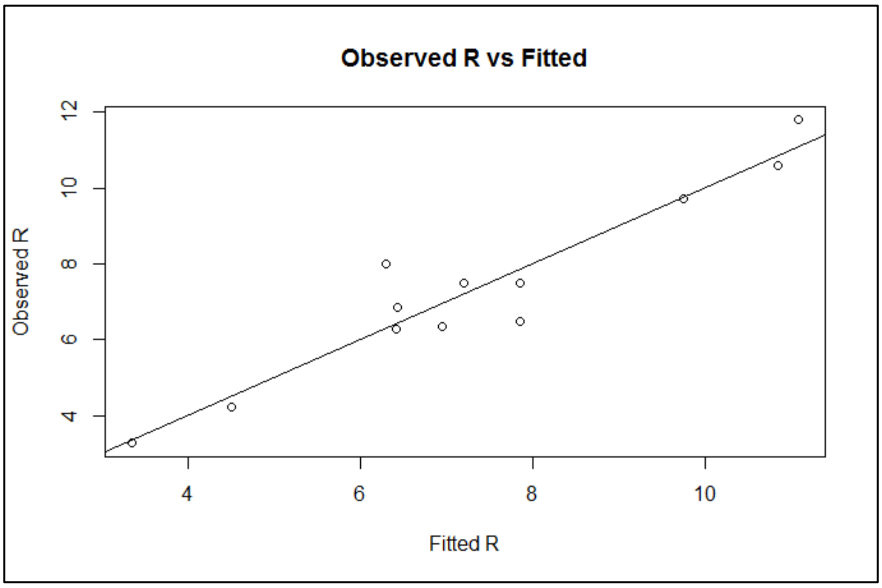

Figure 5: Observed versus predicted R.

MODEL VERIFICATION

In order to verify the model (the power to predict *R* and T_c with data not used on the regression equation estimation), events from different watersheds not used on the modeling process were selected following the same methodology as described on this paper. The total runoff was separated and the initial and constant precipitation were estimated using HEC-HMS. Appendix B shows the hydrograph comparisons between observed and estimated. It demonstrates satisfactory results for the watersheds used. However, *It is important to note that this is not best way to very to verify the model.* For a more accurate verification procedure, it is recommended to use watersheds well studied (if possible) and do not enter any optimized parameter but only calculated parameters.

CONCLUSIONS

It was possible to model regression equations with satisfactory power of explanations for the storage coefficients and time of concentration parameters. The validation of the equations shows that they are valid for the range of geomorphological characteristics used for developing the equations and the characteristics of events used (runoff between and inclusive within 0.4 in and 1.5 in). However, the validation method should be questioned and other validation methods should be employed; the optimization results for SCS hydrographs show that this method is not as accurate as Clark's hydrograph. It was also shown that Clark's approach performs slightly better than the Snyder approach. Further efforts are suggested in the following section. These suggestions are meant to provide guidance in bettering the efforts made to allow for the use of these regression equations and the methodologies used to create them.

SUGGESTIONS FOR FUTURE STUDIES AND SOURCES OF ERRORS

- Some interesting extreme events that happened before 2007 are not modeled in this study. Since those events are important to modify the existing models or to develop new extreme event regression models. The procedure and criteria for streamgage selection would be revised to include stations with older data.
- The research should be extended to the entire state of New York, providing additional precipitation data and broader geographical application.
- Evaluate the effect of selecting the closest precipitation station using the geometric center of the watershed as the reference point instead of streamgage location.
- Study outlying observations as a source of insight into extreme conditions or important causative relationships (Helsel and Hirsch, 2002).
- Investigate non-linear models such as Support Vector Machine models.
- Investigate how the alpha parameter for baseflow separation differs seasonally, and evaluate seasonal models using seasonally-adjusted alpha parameters.
- Evaluate different precipitation loss methods.

Sources of error

- Uncertainties in the temporal distribution of effective rainfall: location of rain gages to determine the watershed-average rainfall and temporal rainfall distribution are commonly 0.8 to 25 mi outside the watershed, where runoff data are available.

- Significant differences between the optimized parameters for different events for the same watershed. Future study should evaluate seasonal models.
- Error inherent in measuring precipitation and flow.

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APPENDIX A – TABLES

Table 1: Summary of events used on the modeling process

Station	Number of events	Event date	Precipitation (in)	Runoff (in)	Tc (h)	Average Tc (h)	R (h)	Average R (h)	Difference in total runoff (%)	Difference in Peak Flow (%)	Difference in time of peak (min)
Events used for developing of regression equations											
Hollow Tree Brook at lanesville NY (01362342)	3	December 23, 2007	2.8	0.605	3.218	5.293	9.539	9.712	-4.13	3.8	15:00
		October 28, 2006	3.2	0.412	6.007		13.109		4.37	0.4	0:00
		April 16, 2011	2.5	0.907	6.656		6.487		1.32	-0.4	15:00
Mongaup River at Mongaup Valley NY (01432900)	4	November 19, 2003	1.9	0.443	10.001	8.272	8.202	6.867	1.58	0.7	0:00
		September 30, 2010	4.7	0.853	7.281		5.396		-10.9	-1.8	0:00
		December 20, 2012	2.3	0.509	6.502		7.52		-5.7	2.6	0:00
		August 27, 2011	5.4	1.132	9.304		6.349		-1.94	1.4	-15:00
Cajoharie Creek near Cajoharie NY (01349150)	2	May 8, 2012	2.3	0.843	3.831	4.915	5.305	6.267	-0.36	2.2	15:00
		October 25, 2005	1.3	0.842	6		7.228		0.95	-4.5	0:00
Esopus Creek at Allaben NY (01362200)	3	December 23, 2007	2.9	0.499	5.148	3.553	10.999	11.792	-1.8	-0.1	0:00
		October 28, 2006	3.2	0.498	2.504		13.017		0.4	4.1	0:00
		October 27, 2007	2.5	0.349	3.007		11.359		0.29	-1.6	0:00
Trout Creek near Trout Creek NY (0142400103)	1	October 24, 2009	2.5	0.469	1.505	1.505	3.27	3.27	-10.45	0.5	0:00
Glowegee Creek at West Milton NY (01330000)	3	October 29, 2003	1.5	0.443	9.736	8.917	4.996	4.239	-7.45	-1.7	15:00
		September 30, 2010	3.6	0.801	8.351		3.854		-5.12	-3.5	0:00
		August 28, 2011	3.4	1.042	8.666		3.867		-11.71	-3.7	-15:00
West Branch Neversink River at	6	June 18, 2009	2	0.531	3.784	2.443	11.442	6.364	1.69	1.9	15:00
		December 11, 2008	2.2	0.959	2.118		5.013		-0.94	1.3	15:00

Station	Number of events	Event date	Precipitation (in)	Runoff (in)	Tc (h)	Average Tc (h)	R (h)	Average R (h)	Difference in total runoff (%)	Difference in Peak Flow (%)	Difference in time of peak (min)
Frost Valley NY (01434498)		October 25, 2008	3.3	0.673	2.116		5.882		-4.9	2.2	-15:00
		October 28, 2006	2.4	0.989	1.573		3.997		-11.02	0.3	-15:00
		May 12, 2006	2.6	0.538	1.772		6.988		-5.2	-2.4	-15:00
		December 23, 2004	1.4	0.524	3.293		4.859		-2.67	-4.1	0:00
Never Sink near Claryville NY (01435000)	5	November 29, 2005	2.1	1.111	2.84	2.582	4.034	6.493	-10.89	-2.6	0:00
		September 14, 2006	2.9	0.76	2.543		8.999		-6.58	-3.6	-15:00
		October 28, 2006	2.6	1.137	1.406		5.988		-5.89	-2.9	-15:00
		November 16, 2006	1.5	0.73	3.822		8.267		-1.37	-3.4	15:00
		October 25, 2008	3.2	0.827	2.301		5.178		-9.31	-3.6	0:00
Rondout Creek near Lowes Corners NY (01365000)	2	September 23, 2003	2.5	0.506	1.862	1.992	7.005	7.492	-1.19	3.1	-15:00
		December 11, 2003	1.5	0.564	1.982		7.98		-2.48	-1.5	15:00
West kill Below Hunter Brook near Spruceton NY (01349711)	3	December 23, 2007	3	0.97	2.6	1.721	7.387	7.495	3.09	-4.7	15:00
		October 25, 2008	4.8	0.771	1.187		6.899		-0.13	4	15:00
		October 28, 2006	3.4	0.633	1.377		8.2		-3.63	1.7	-15:00
East Kill near Jewett Center NY (01349700)	4	October 27, 2007	2.5	0.525	1.881	2.978	8.429	7.987	-2.86	-2.3	15:00
		December 23, 2007	3	1.007	4.479		7.328		-2.68	-1.7	-15:00
		October 25, 2008	5	0.789	3.197		7.002		0.13	-4	15:00
		December 2, 2009	2.9	0.53	2.354		9.19		-3.77	-1.8	-15:00
Little Beaver Kill at Beechford near Mount Tremper NY (01362497)	5	December 23, 2007	3	1.111	2.4	0.752	12.604	10.605	5.58	3.2	15:00
		April 22, 2006	2.6	0.859	0.8		13		1.86	2.2	-15:00
		November 16, 2006	2.8	0.621	0.149		11.226		3.38	2.25	15:00
		May 12, 2006	4.2	1.017	0.143		8.065		-2.46	-0.9	-15:00
		March 22, 2010	2.7	1.262	0.267		8.129		2.77	2.1	15:00
Events used on the verification of the model											
Birch Creek at Big Indian NY (13621955)	1	March 22, 2010	2.7	0.788	3.6		4.92		-3.3	-17.6	0:00

Station	Number of events	Event date	Precipitation (in)	Runoff (in)	Tc (h)	Average Tc (h)	R (h)	Average R (h)	Difference in total runoff (%)	Difference in Peak Flow (%)	Difference in time of peak (min)
West kill near West Kill NY (1349810)	3	April 16, 2011	2.5	0.798	3.438		8.902		-7.27	-9.4	45:00
		March 22, 2010	2.7	1.403					-0.21	-34.3	3:15
		December 23, 2007	3	0.86					-7.21	1.7	3:30
Bush Kill Blw Malt by Hollow Brook at West shokan NY (1363382)	1	May 12, 2006	2.6	1.188	1.469		9.455		-15.66	-20.9	15:00
East br Neversink River near Claryville NY (1434017)	2	August 3, 2003	2.1	0.667	5.214		6.257		-15.59	2.9	18:15
		May 11, 2006	2.6	1.052					1.05	-6.6	45:00
Biscuit Brook above Pigeon brook at Frost Valley NY (1434025)	3	December 11, 2003	1.7	1.011	1.257		3.738		-37.49	31.3	2:30
		September 14, 2006	2.7	0.656					-43.75	19.2	30:00
		April 3, 2009	0.8	0.422					-37.68	25.5	0
Chestnut Creek at Grahamsville NY (1365500)	3	December 26, 2009	1.2	0.492	6.268		2.582		-26.63	-5.2	1:45
		March 22, 2010	1.9	0.743					-15.61	-11.5	4:15
		December 11, 2003	1.7	0.586					-20.14	-0.6	1:15
*West Branch Neversink River at Frost Valley NY (1434498)	1	July 29, 2009	5.1	1.801	3.659		6.956		-13.44	-37.24	1:15
*Little Beaver Kill at Beechford near Mount Tremper Ny (1362497)	1	March 28, 2010	4.1	1.174	5.241		10.832		0.94	20.22	1:00

Note: The negative signs in difference in time of peak indicates the estimated peak flow is 15 minutes before the observed
* Equation also used for regressing the equations

Table 2: Summary of geomorphologic characteristics of watersheds used on the modeling process

Station	Slope 10-85 (ft/mi)	Channel length (mi)	Lag factor	Basin storage (%)	Urban land (%)	Basin slope (ft/mi)	Forest coverage (%)	Drainage area (mi^2)	Slope ratio	Basin perimeter (mi)	Circulatory ratio	Used precipitation station
Stations used for developing of regression equations												
Hollow Tree Brook at lanesville NY (01362342)	615	2.38	0.0035	0.0178	0	2490	100	1.949	0.247	6.935	0.509	308406
Mongaup River at Mongaup Valley NY (01432900)	26.5	19	0.75	3.15	3.32	508	78.1	76.852	0.052	64.908	0.229	305435
Canajoharie Creek near Canajoharie NY (01349150)	21.2	18.9	1.06	0.77	0.42	448	37.1	59.463	0.047	56.880	0.231	302953
Esopus Creek at Allaben NY (01362200)	80	14.2	0.15	0.0321	0.21	1670	98.7	63.629	0.048	49.784	0.323	308406
Trout Creek near Trout Creek NY (0142400103)	68.9	8.55	0.11	0.0912	0.12	825	80.4	20.160	0.084	27.017	0.347	302454
Glowegee Creek at West Milton NY (01330000)	34.7	14.4	0.44	7.35	1.48	348	76.4	24.905	0.100	34.399	0.264	308586
West Branch Neversink River at Frost Valley NY (01434498)	71.4	14.6	0.16	0.15	0.0212	1210	99.5	33.879	0.059	42.067	0.241	301521
Never Sink near Claryville NY (01435000)	61.8	17.3	0.22	0.0862	0.0827	1190	99.3	66.541	0.052	53.413	0.293	301521
Rondout Creek near Lowes Corners NY (01365000)	107	12.8	0.11	0.0745	0.0177	1470	98.9	38.461	0.073	38.587	0.325	301521
West kill Below Hunter Brook near Spruceton NY (01349711)	485	3.19	0.00591	0	0	1950	99.9	4.863	0.249	11.930	0.429	308406
East Kill near Jewett Center NY (01349700)	45.2	16.6	0.28	0.84	0.12	914	94.2	35.573	0.049	42.862	0.243	308406
Little Beaver Kill at Beechford near Mount Tremper Ny (01362497)	25.7	9.4	0.25	1.92	0.0949	1030	95.8	16.658	0.025	25.352	0.326	308406
Max	615	19	1.06	7.35	3.32	2490	100	76.852	0.249	64.908	0.509	
Min	21.2	2.38	0.0035	0	0	348	37.1	1.949	0.025	6.935	0.229	
Average	136.867	12.61	0.295	1.207	0.491	1171.083	88.192	36.911	0.090	37.845	0.313	
Station used for verification of regressed equations												

Station	Slope 10-85 (ft/mi)	Channel length (mi)	Lag factor	Basin storage (%)	Urban land (%)	Basin slope (ft/mi)	Forest coverage (%)	Drainage area (mi^2)	Slope ratio	Basin perimeter (mi)	Circulatory ratio	Used precipitation station
Birch Creek at Big Indian NY (013621955)	183	7.4	0.0365	0.0386	0.38	1350	97.2	12.500	0.136	20.903	0.360	301521
West kill near West Kill NY (01349810)	108	11.9	0.0993	0.16	0.21	1600	96.5	26.900	0.068	35.350	0.271	308406
Bush Kill Blw Malt by Hollow Brook at West shokan NY (01363382)	207	6.42	0.0292	0.00181	0.0104	2030	99.9	17.000	0.102	24.138	0.367	301521
East br Neversink River near Claryville NY (01434017)	86.3	13.2	0.14	0.00135	0.00874	1230	99.8	23.000	0.070	38.813	0.192	301521
Biscuit Brook above Pigeon brook at Frost Valley NY (01434025)	380	3.56	0.0102	0	0	1400	100	3.752	0.271	10.402	0.436	301521
Chestnut Creek at Grahamsville NY (01365500)	241	6.51	0.0279	1.59	0.56	801	88.8	21.200	0.301	35.269	0.214	301521
Max	380	14.6	0.25	1.92	0.56	2030	100	33.879	0.301	42.067	0.436	
Min	25.7	3.56	0.0102	0	0	801	88.8	3.752	0.025	10.402	0.192	
Average	139.95	9.699	0.116	0.593	0.140	1289.100	97.280	20.543	0.112	29.971	0.297	

Note: Two different events not used on the regression process from stations 01434498 and 01362497 (used for regressing the equations) were included on the verification.

Table 3:Multi-collinearity results for the final R regression equation

Variable	VIF
Basin storage	2.88
Basin slope	7.43
Forest	2.76
Slope ratio	1.38
Basin perimeter	2.06

APPENDIX B – GRAPHS

1. **Hydrographs from Section 12**

Figure 1: Observed and predicted hydrograph for precipitation event on Apr. 16, 2011 in Station 01349810

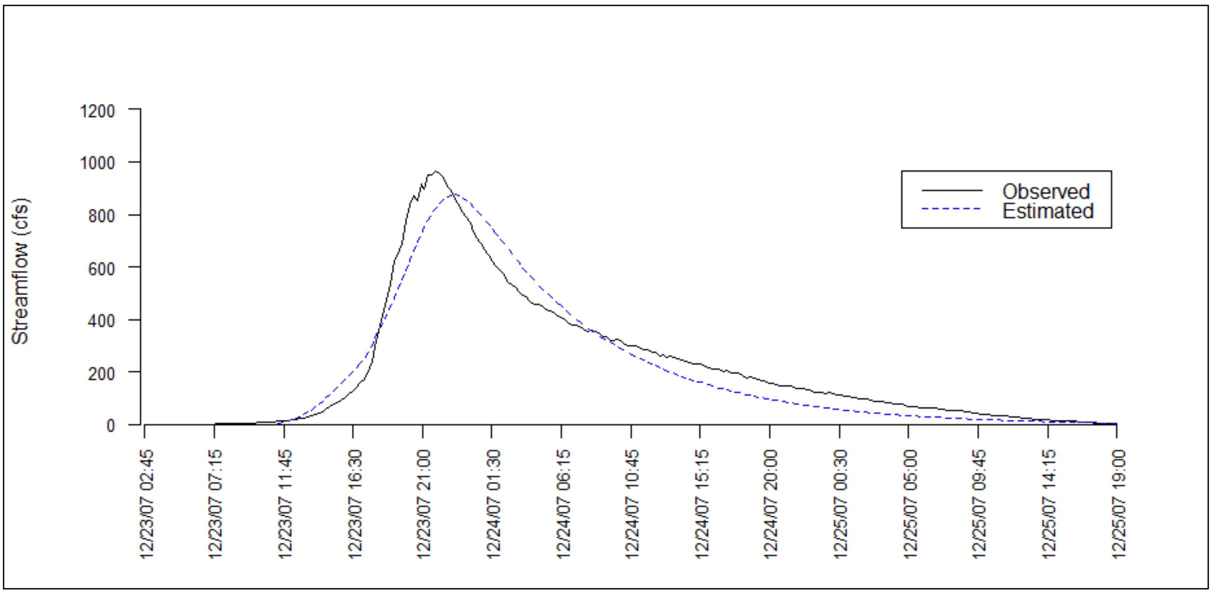


Figure 2: Observed and predicted hydrograph for precipitation event on Mar 22, 2010 in station 01349810

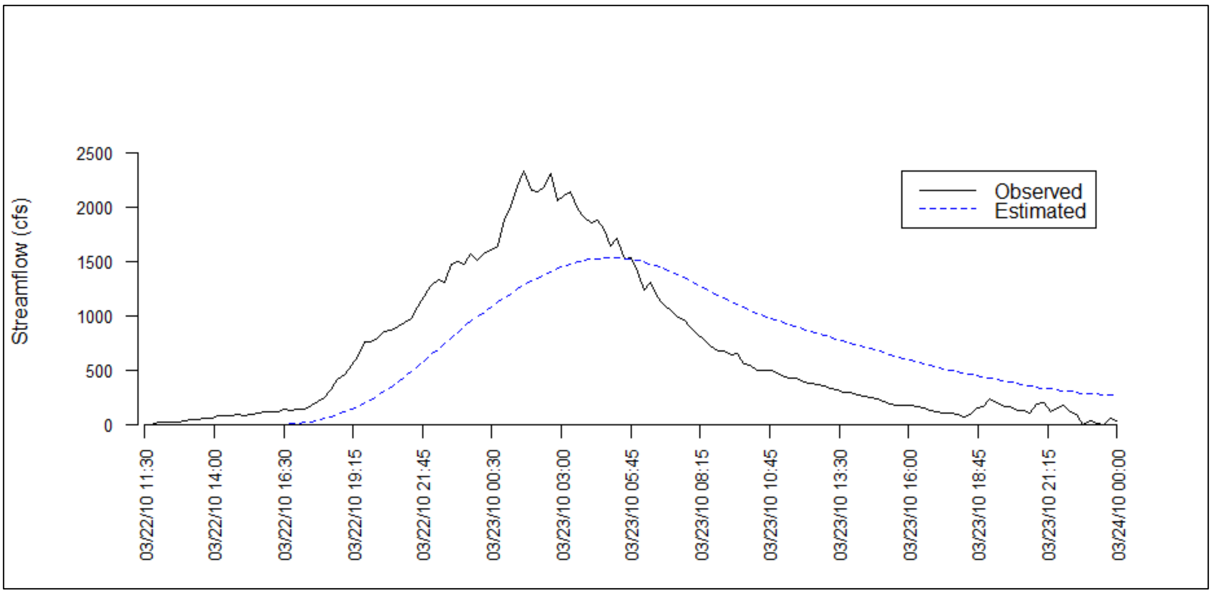


Figure 3: Observed and predicted hydrograph for precipitation event on Mar. 23, 2010 in Station 013621955

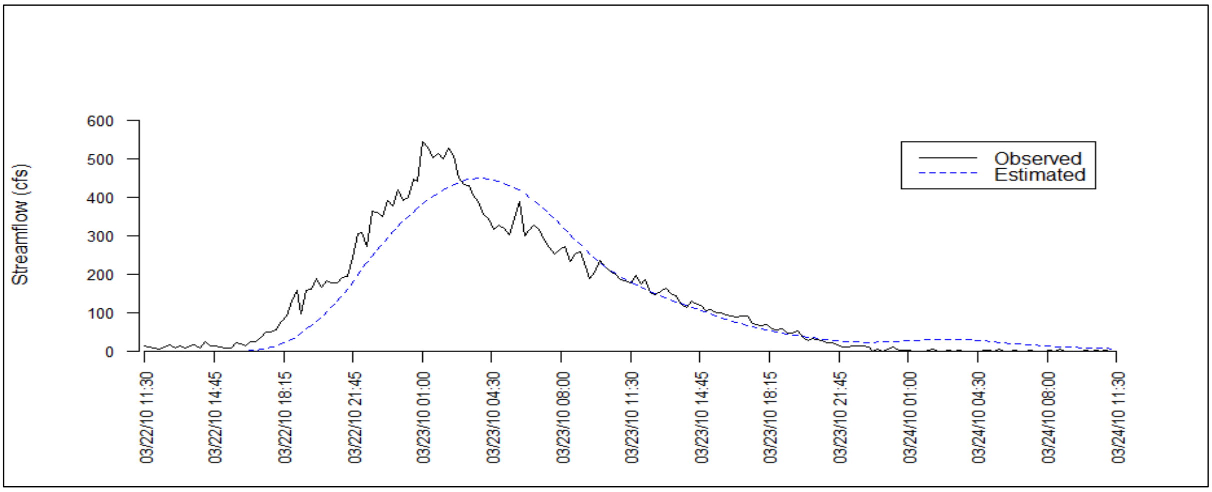


Figure 4: Observed and predicted hydrograph for precipitation event on Mar. 28, 2010 in Station 01362497

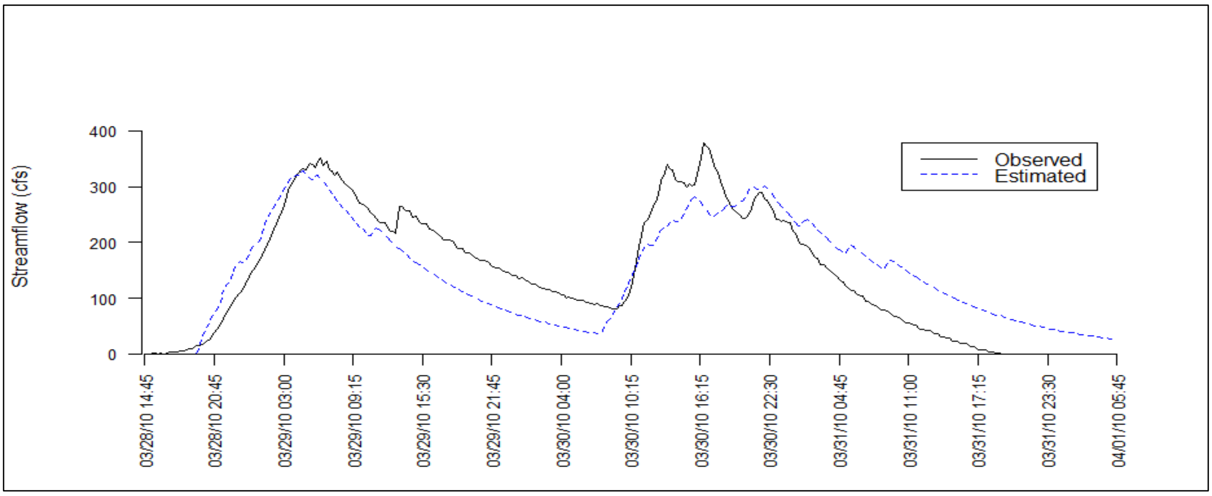


Figure 5: Observed and predicted hydrograph for precipitation event on Dec. 10, 2003 in Station 01365500

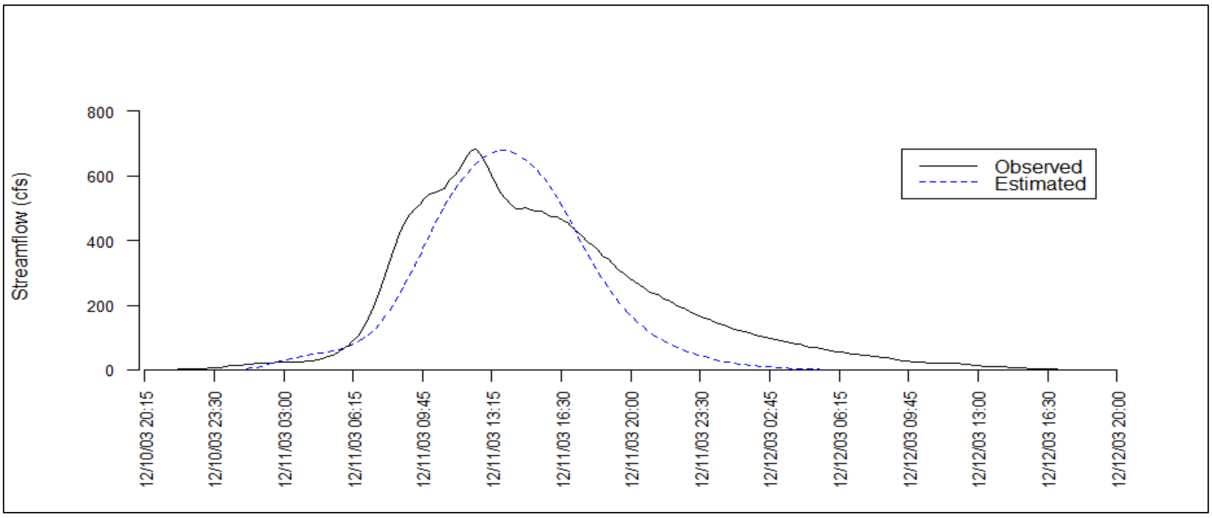


Figure 6: Observed and predicted hydrograph for precipitation event on Mar. 22, 2010 in Station 01365500

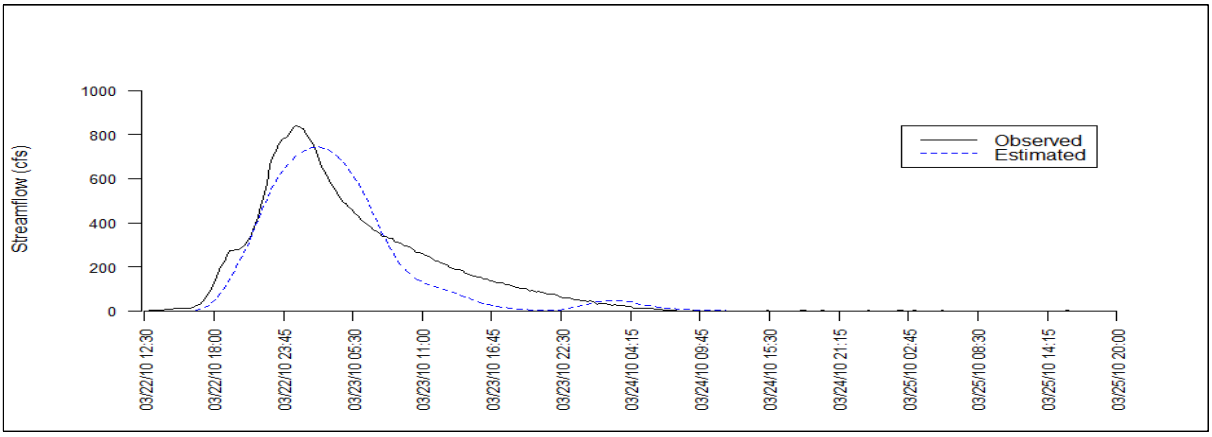


Figure 7: Observed and predicted hydrograph for precipitation event on Dec. 26, 2009 in Station 01365500

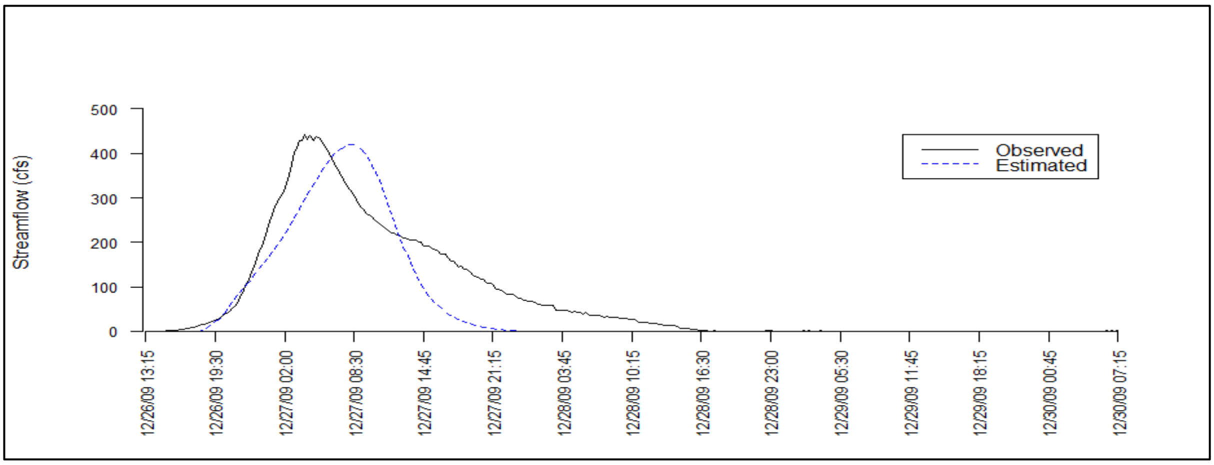


Figure 8: Observed and predicted hydrograph for precipitation event on May. 11, 2006 in Station 01434017

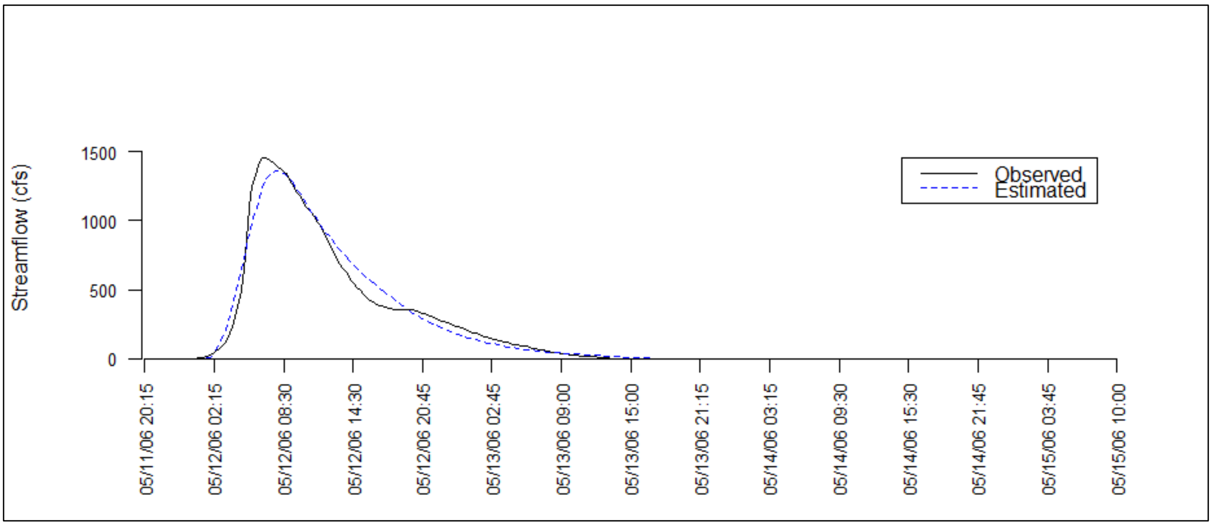


Figure 9: Observed and predicted hydrograph for precipitation event on Apr. 3, 2009 in Station 01434025

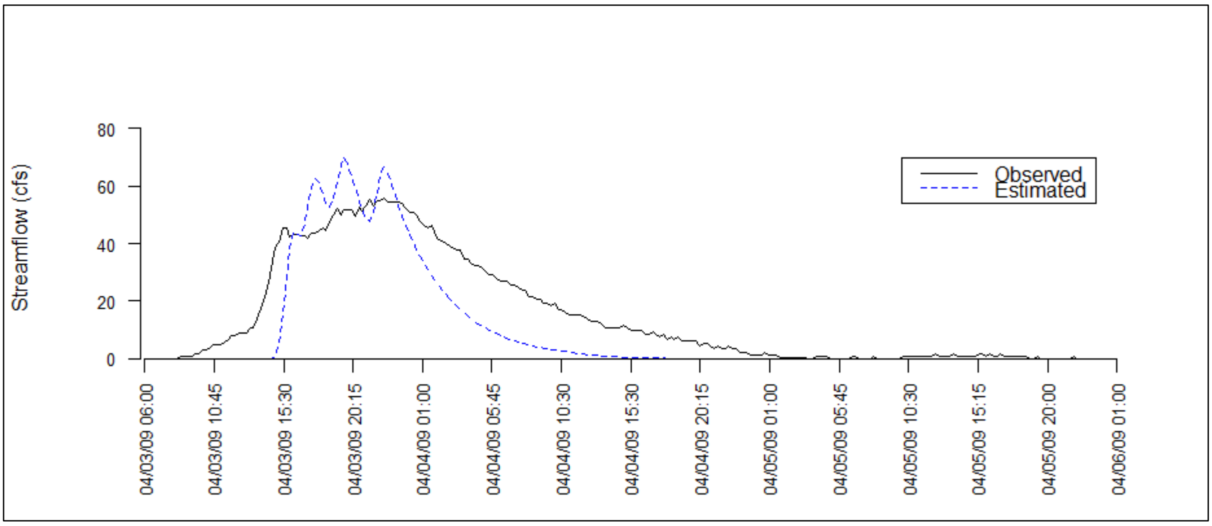


Figure 10: Observed and predicted hydrograph for precipitation event on Dec. 10, 2003 in Station 01434025

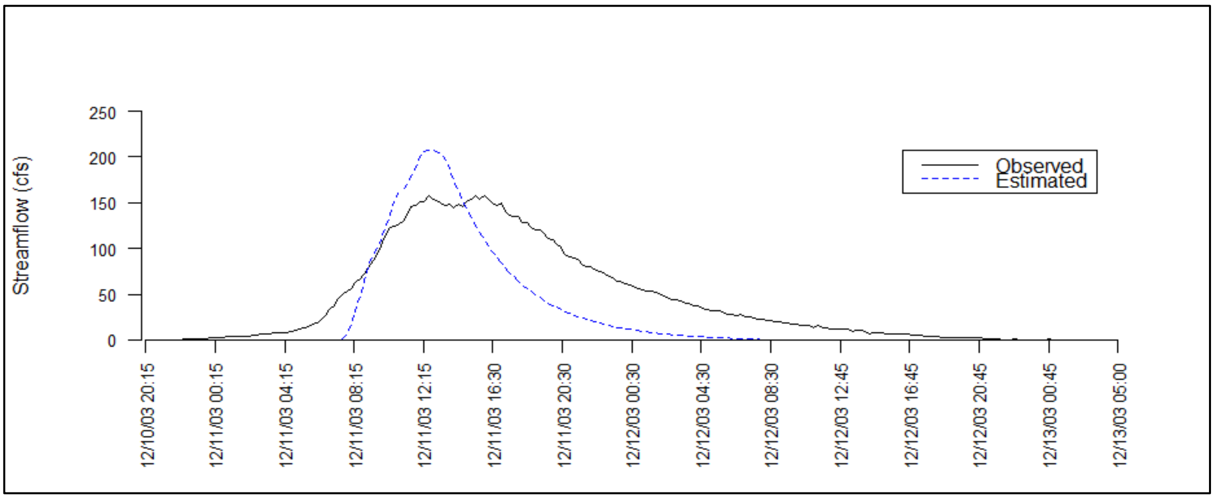
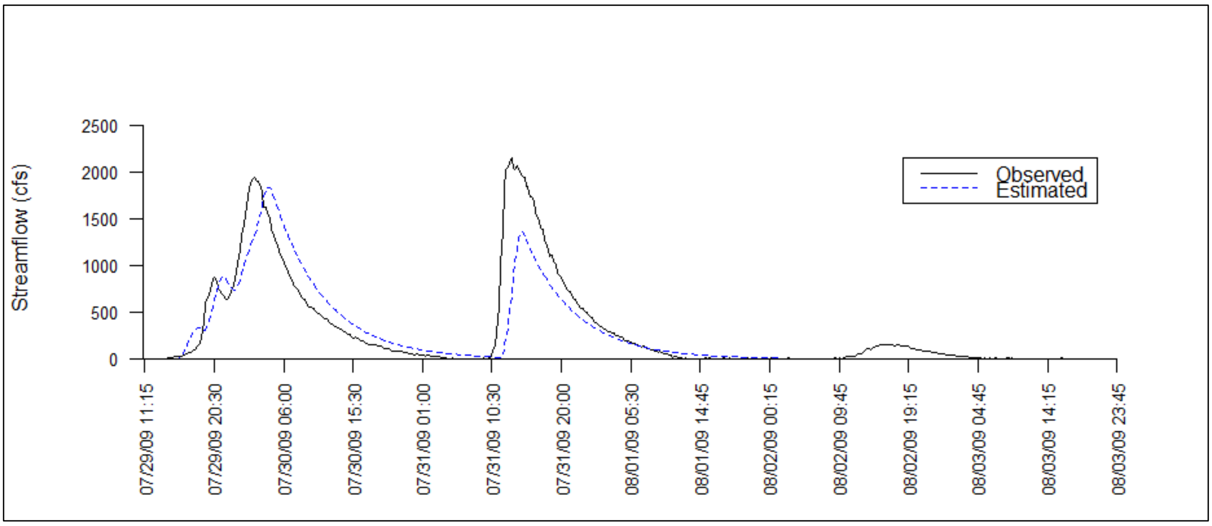


Figure 10: Observed and predicted hydrograph for precipitation event on Jul. 29, 2009 in Station 01434498



2. Hydrographs from Section 11.3

Figure 1: Observed, Clark and SCS hydrograph for precipitation event on Apr. 22, 2006 in Station 01362497

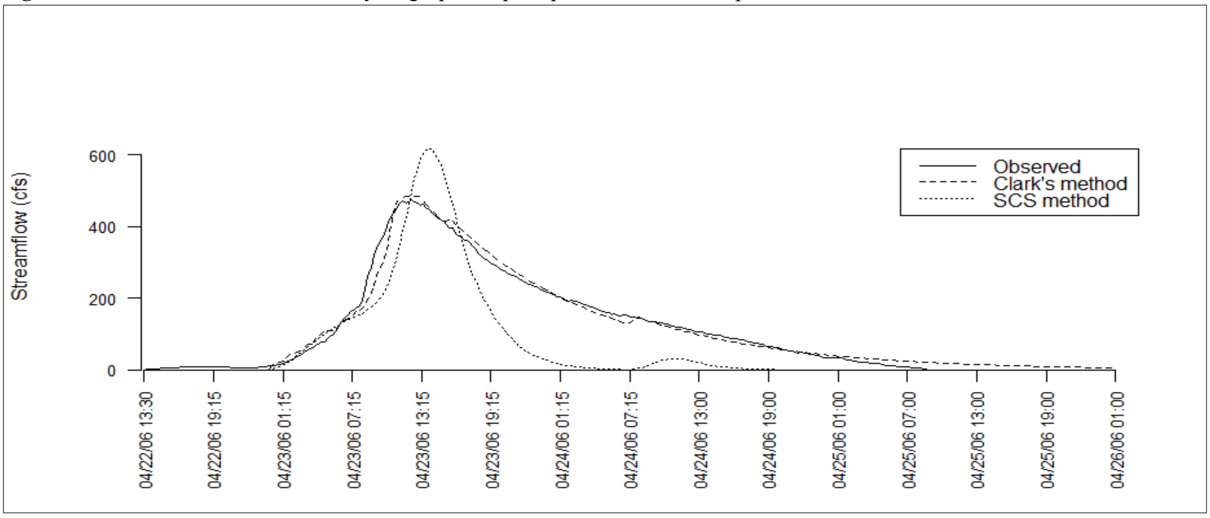


Figure 2: Observed, Clark and SCS hydrograph for precipitation event on Nov. 19, 2003 in Station 01432900

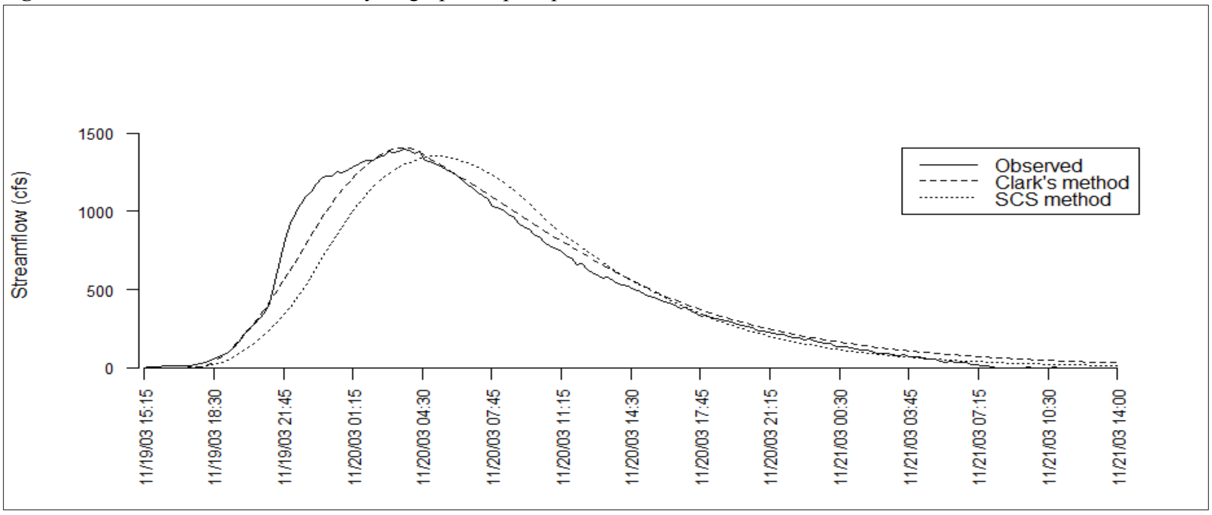


Figure 3: Observed, Clark and SCS hydrograph for precipitation event on Aug. 27, 2011 in Station 01432900

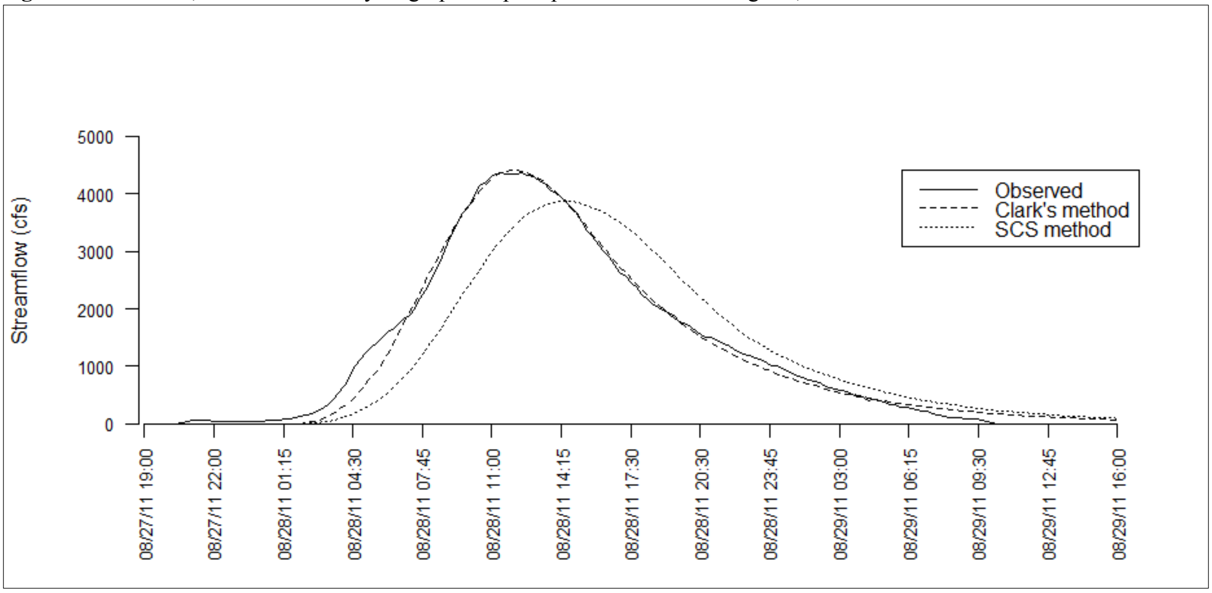


Figure 4: Observed, Clark and SCS hydrograph for precipitation event on May 11, 2006 in Station 01434498

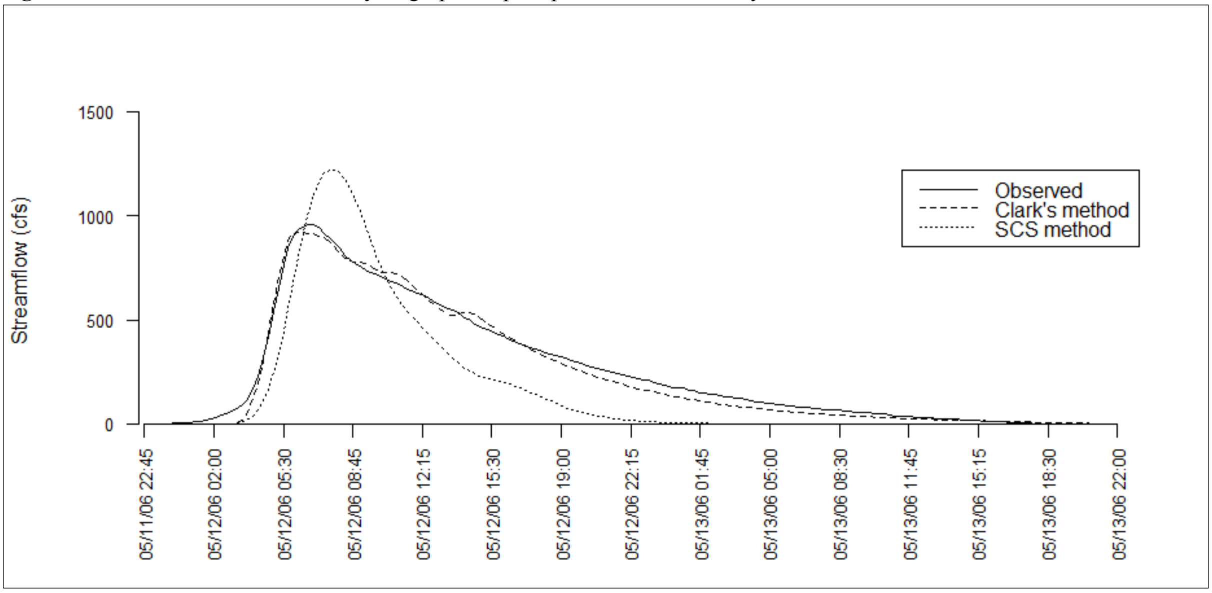


Figure 5: Observed, Clark and SCS hydrograph for precipitation event on Jun. 17, 2009 in Station 01434498

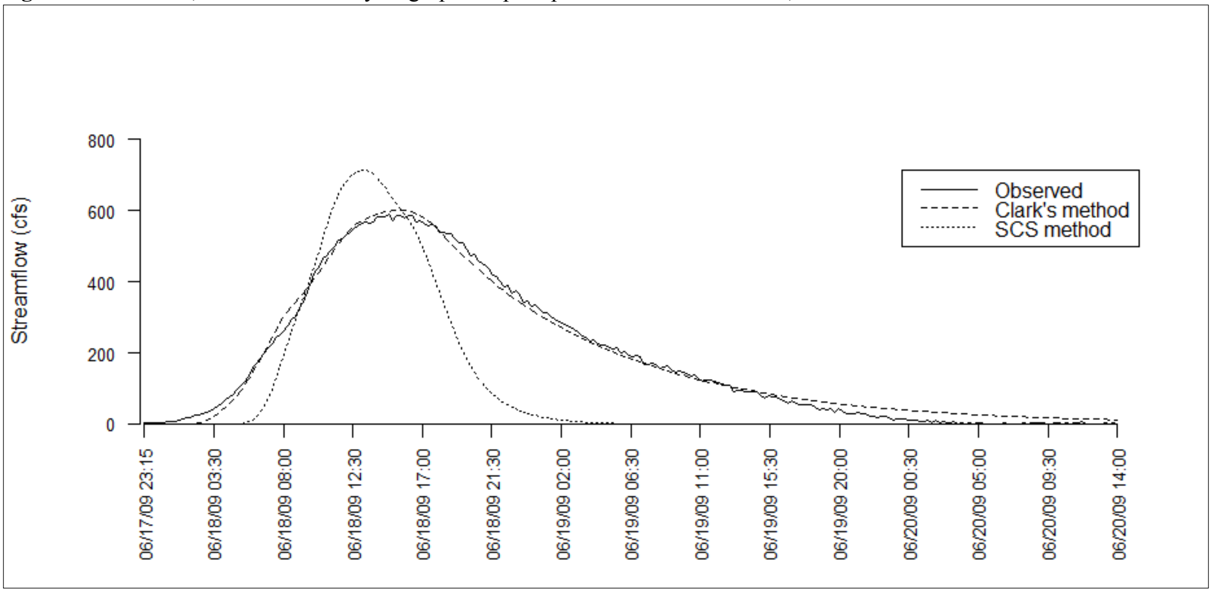
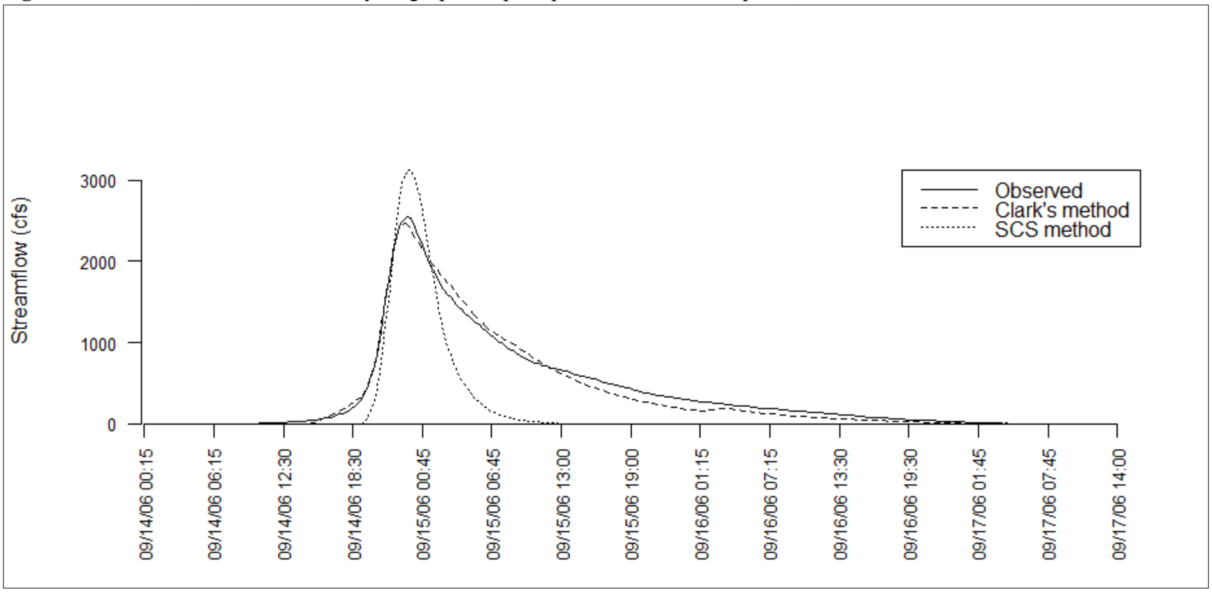


Figure 6: Observed, Clark and SCS hydrograph for precipitation event on Sept.14, 2006 in Station 01435000



3. Other Graphs

Figure 1: Scatter plots: T_c vs. Geomorphological Characteristics (untransformed variables)

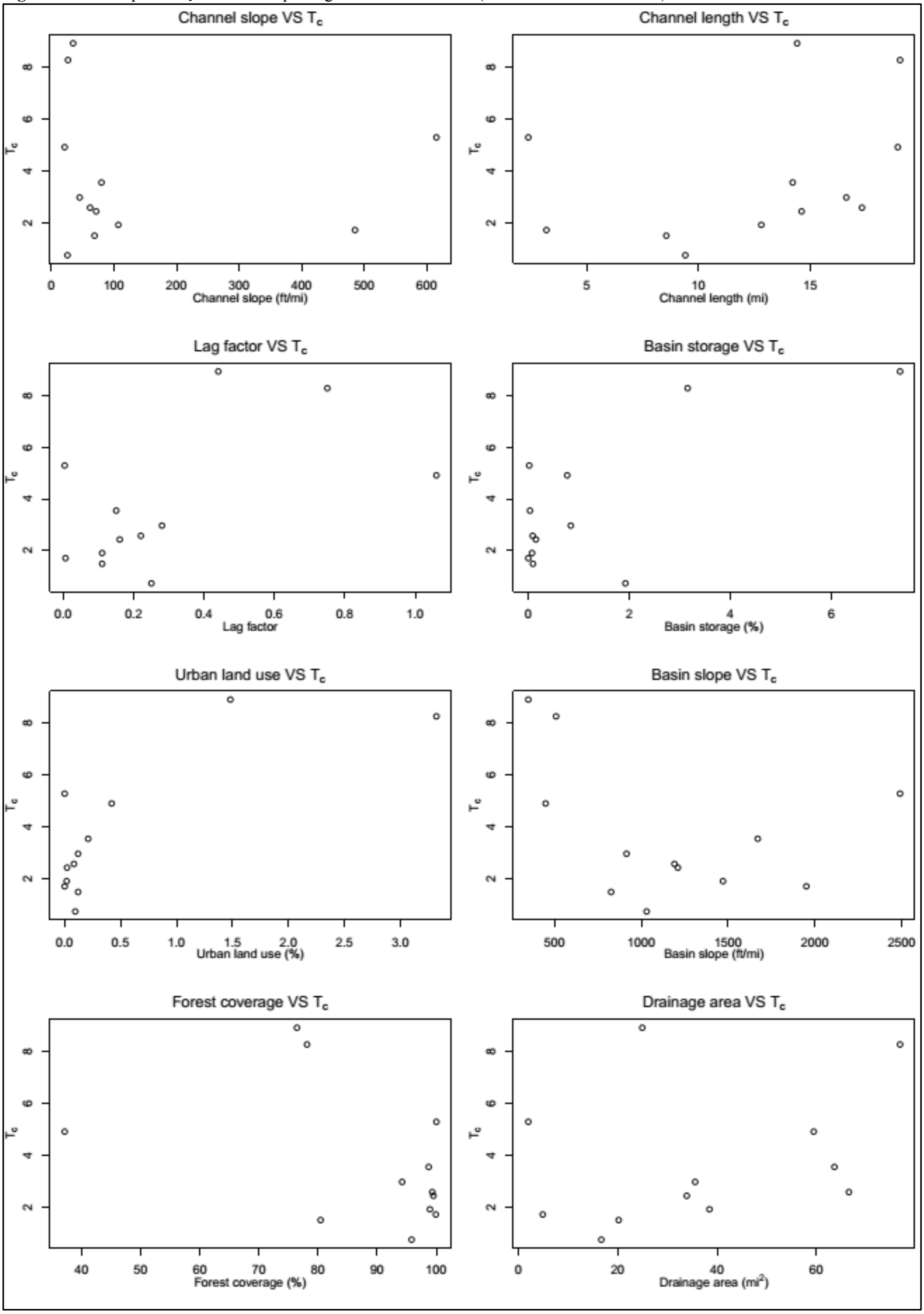


Figure 2: Scatter plots: Transformed T_c vs. Geomorphological Characteristics

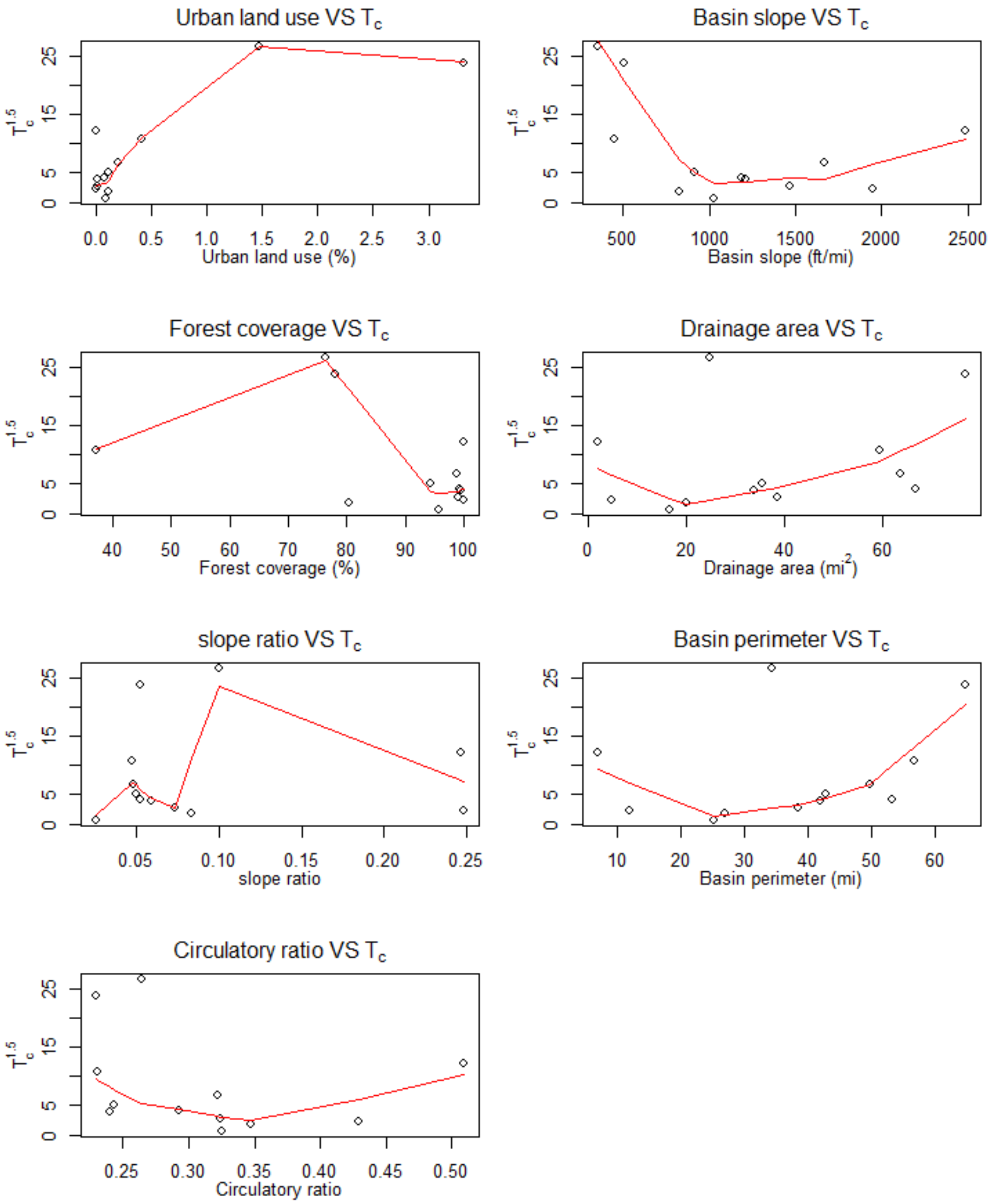
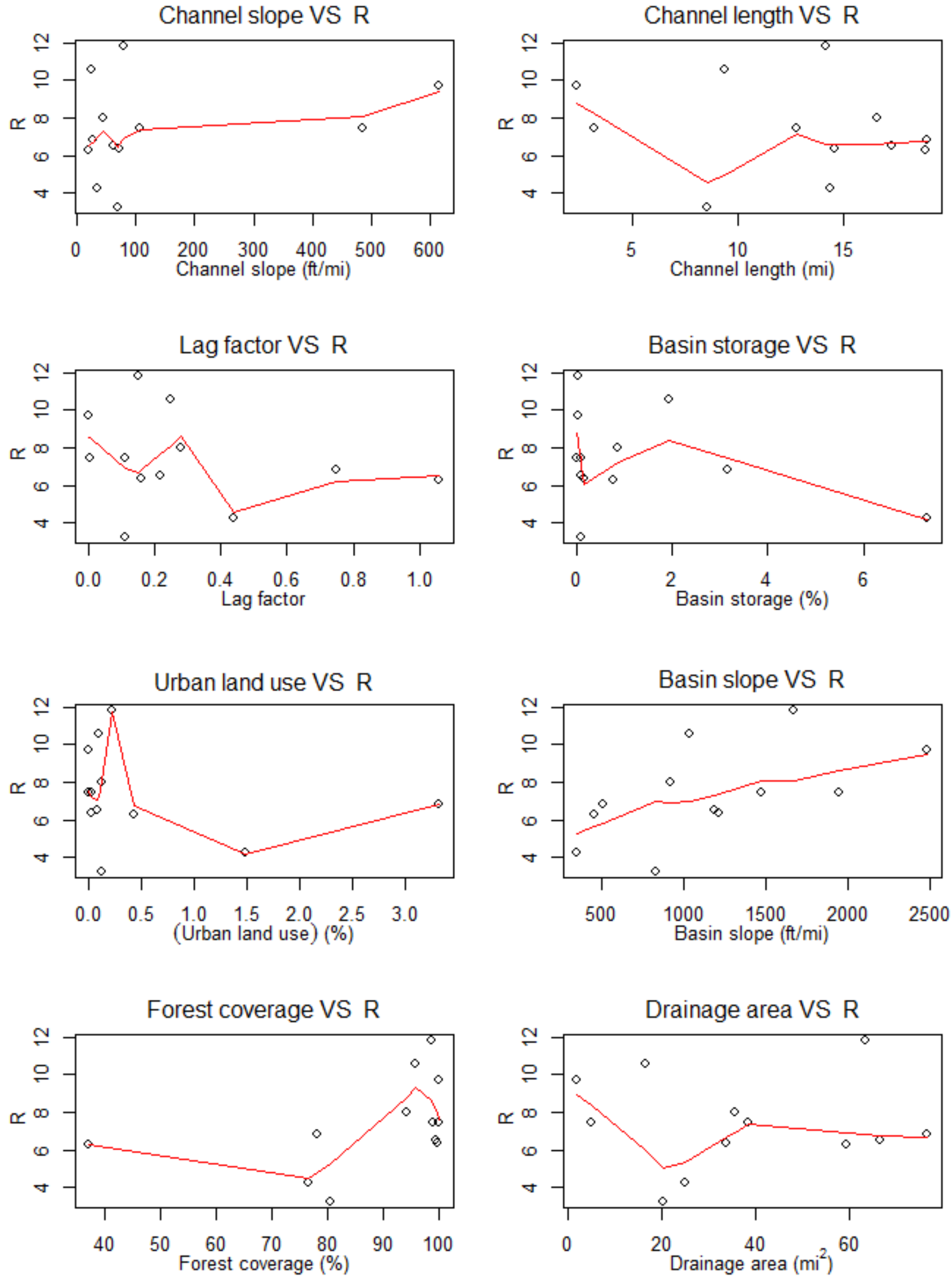


Figure 3: Scatter plots: R vs. Geomorphological Characteristics



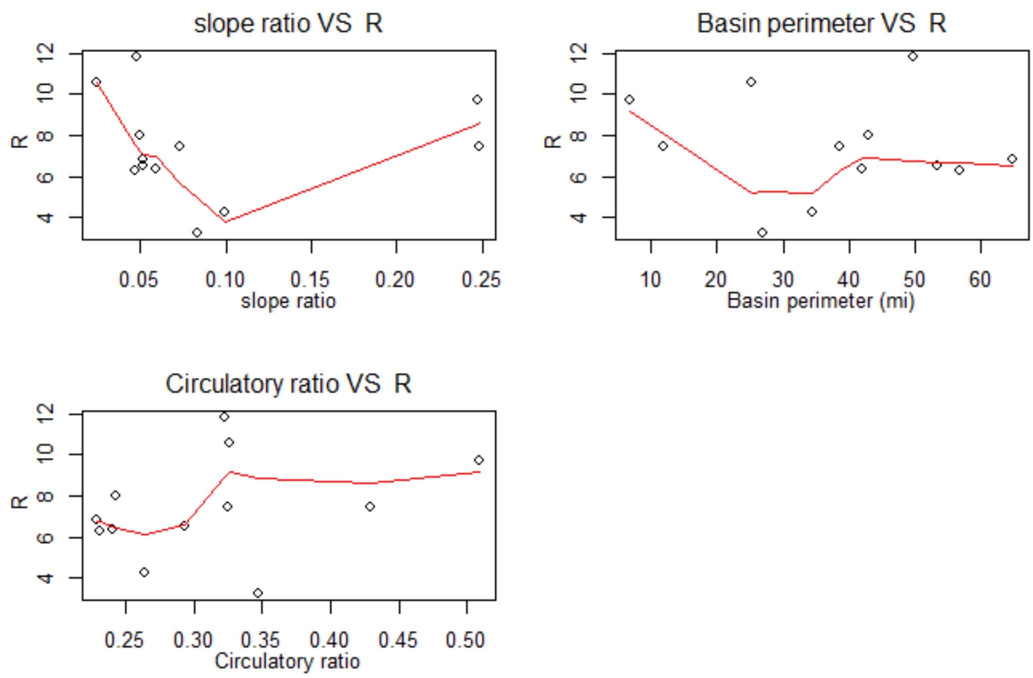


Figure 4: Q-Q plot for initial T_c model

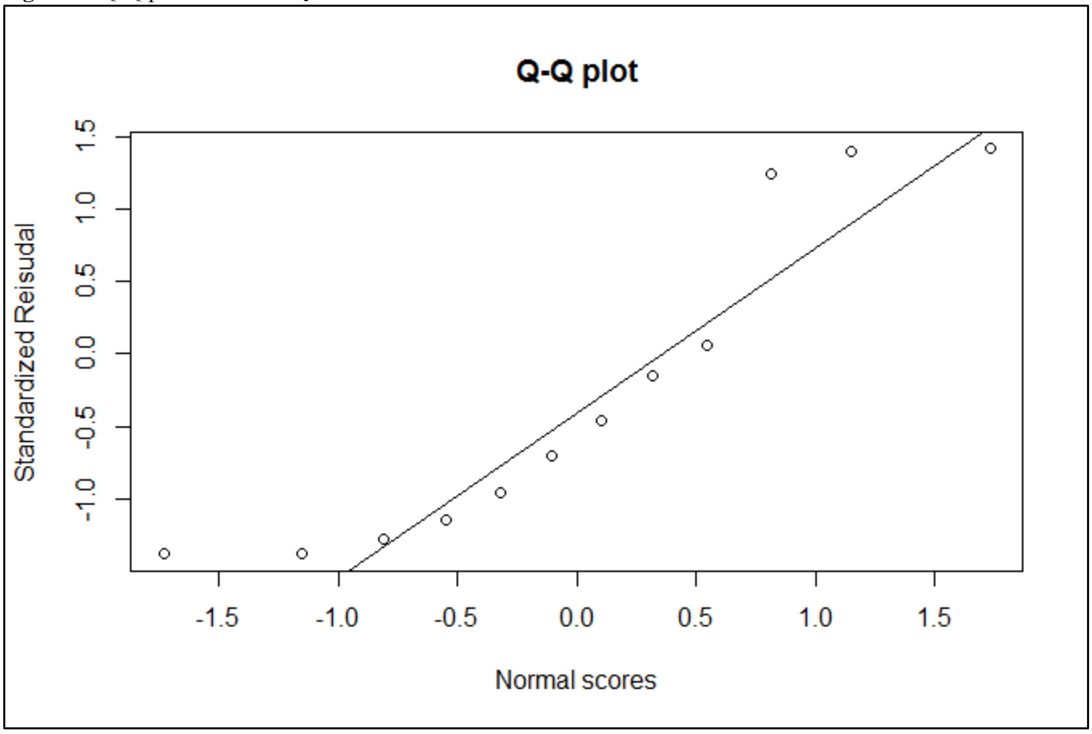


Figure 5: Q-Q plot and Residuals vs. Fitted for Final T_c model

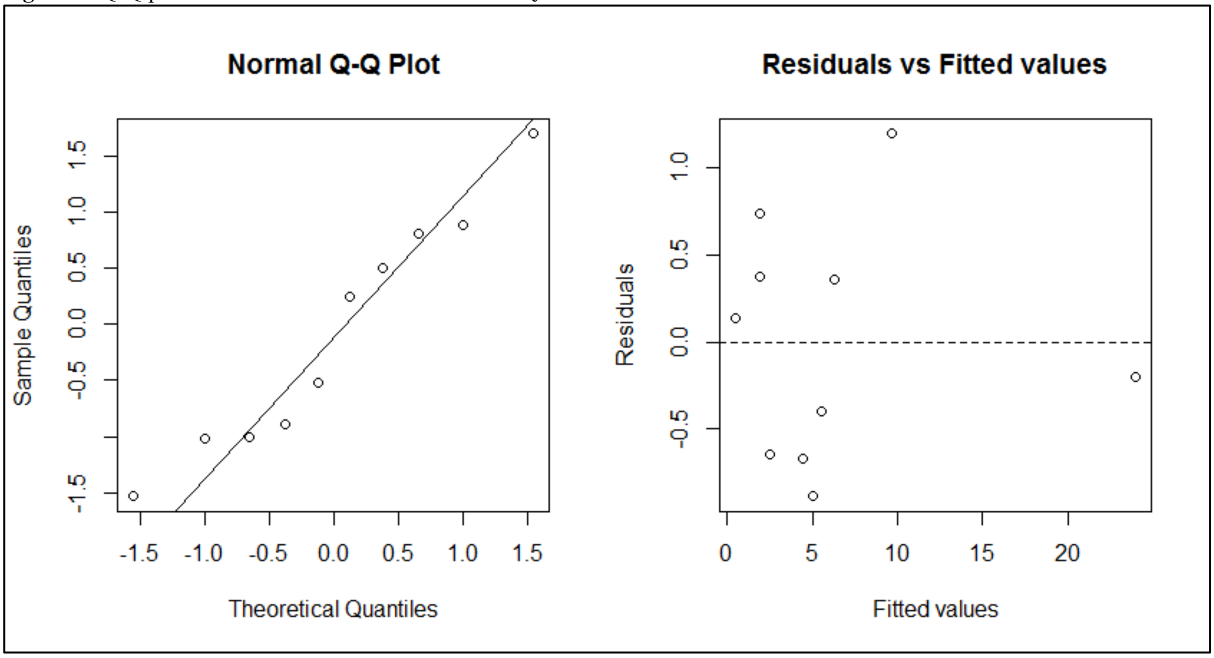
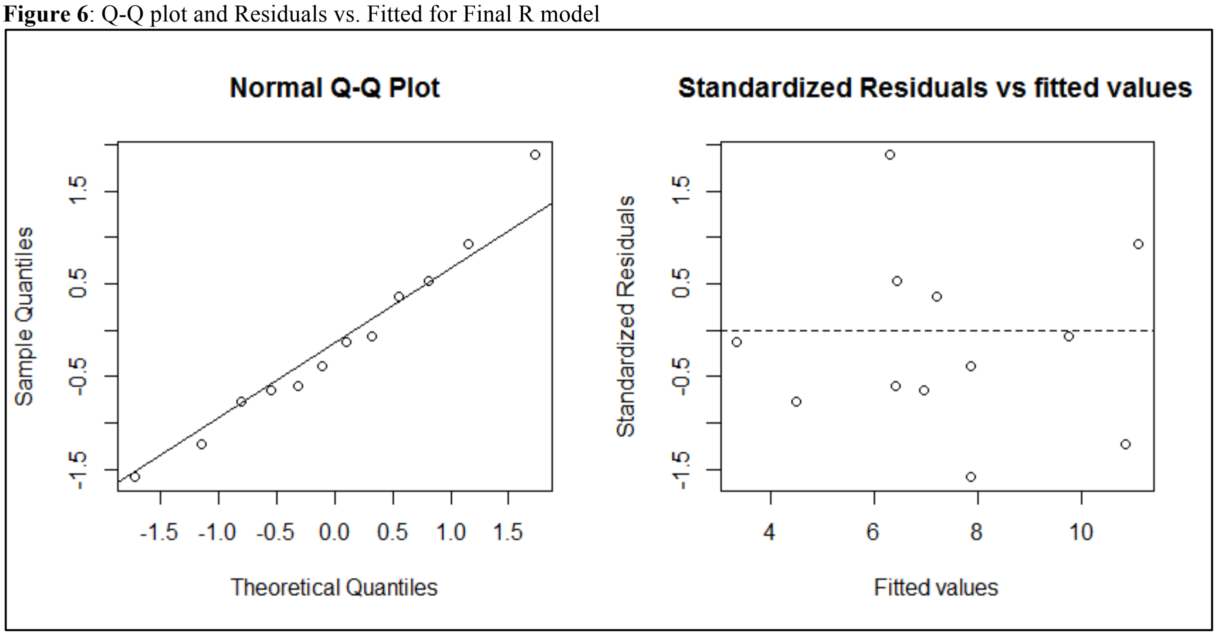


Figure 6: Q-Q plot and Residuals vs. Fitted for Final R model



APPENDIX C – CODES

The process of preparing data (e.g. converting at the convenient format and joining precipitation and flow together in one file), choosing and extracting the event may be somewhat toilsome and reptitive. In fact, the methodology applied was to go through the precipitation data, which means going through a spreadsheet file containing usually from 2500 to 3000 rows, choose the precipitation events as defined in the methodology section, generate graphs to check if flow data is consistent with precipitation records for the specified events as well as to certify if event is isolated with single peaks, separate direct runoff from total flow and finally calculate the total direct runoff to verify if it meets the criterion of being above 0.4 and below 1.5in.

Therefore, the process of using computer codes provide a good alternative to speed up the research processes and define a solid method for replicating the results. In this paper, functions were coded in R (R Core Team, 2014) because it offers great flexibility to work with large datasets and do statistics analysis.

In this section all the codes are explained, however, the cold itself is contained in an R file named "All_Fulctions.R".

Function A.1: hydrograph – hydrograph is a slight modification of the function Hydrograph from EcoHydRology package (Fuka et al, 2014). It plots the hydrograph given the dataset. Useful for visually inspecting the selected events. For help on how to use this function, please visit: http://cran.r-project.org/web/packages/EcoHydRology/EcoHydRology.pdf.

It was added the following feature to original function:

- `streamflow5` and `streamflow6`: option to add to more streamflow to the same hydrograph;
- `legends`: option to add legends; this should be a character vector specifying the legend for streamflow in same order of streamflows inputs;
- `dateFormat`: let the user choose the date time series date format to appear on the horizontal graph. See `?strptime` in R for how to use date formats;
- `rotaTexLabels`: Boolean variable defining whether or not labels should be rotated;
- `tickMarks`: numeric variable indicating how many tick marks and labels should appear on the horizontal axis.

Function A.2: baseflow.computation – this function is coded for computation of baseflow according to methodology defined at section 7; the function allows the user to compute baseflows using more the one parameters, therefore also working as a baseflow parameters trials. It is important to note that the core of this function is incorporated from BaseflowSeparation from EcoHydRology package (Fuka et al, 2014).

Inputs are (to use this function it is necessary to source 'hydrograph' first):

- `dataset`: data frame with the following column order: 1 – time series, 2 – precipitation, 3 – flow;
- `passesTrials`: numeric vector: the number of passes the filter will pass through data (see section 7). The user is allowed to specify more than one number of pass, for examples 1, 3, and 5 passes;
- `pdfFile`: character type: the name of the pdf file to be saved containing the graphs;
- `printPDF`: logical: if pdf file containing graphs are to be printed;
- `filter`: numeric vector: the alpha parameters to be used in each pass;
- `returnResult`: logical: if result is to be returned on console;
- `streamLog`: logical: if it is to be printed graph of the flow in logarithmic scale;
- `date.format:` character: string indicating the date format of the time series, in order to do the proper conversions.

Function A.3: join.flow.ppt – this function joins the precipitation and stream flow together using the original precipitation data downloaded from NCDC and stream flow downloaded from USGS instantaneous data archive (http://ida.water.usgs.gov/ida/index.cfm?) or USGS – current condition for streamflows in New York State: http://waterdata.usgs.gov/ny/nwis/current/?type=flow&group_key=basin_cd.

Since codes are designed to work with a certain data format, it is extremely important that the input data have the specified format as coded. It was noticed though, that some streamflow data is composed out of 15min and 5min data instead of 15min only. In addition, it is possible to have some gaps at the time of series of datasets or other times intervals. These and others "errors" would significantly affect the efficiency of the function A.4. Therefore, before joining precipitation and streamflow, function A.3 thoroughly go through the each row of the streamflow dataset attempting to find and fix any source of error in data that could cause function A.4 to not work as designed. This function uses lubridate package (Grolemund and Wickham, 2011).

Inputs:

- `precip`: address to .csv file downloaded from NCDC containing the precipitation data;
- `streamflow`: address to .txt file downloaded from USGS containing the stream flow data.

Function A.4: event.auto.selection – this function attempts to auto select all possible events according to the criteria defined at section 6. Once event is selected, it computes de base and either generates a hydrograph of event or write into a .csv a data frame of the event containing the time series, precipitation, total flow, quick flow (direct runoff) and baseflow. ‘Lubridate’ package (Grolemund and Wickham, 2011) is used in this function to manage time series.

Usage: the user must run the function twice. First, to generate the hydrograph to, from them, select the appropriate filter parameter (see section 7). At the second time, user specify the filter for calculating baseflow as concluded from the graphs from the previous run. At first run user should set `plot.graphs=TRUE` and `write.events=FALSE`; the opposite is true for the second run.

Inputs:

- dataset: address to the file generate by function A.3;
- ppt.threshold: is the total minimum precipitation an event should have in order to be considered suitable;
- peakflow.threshold: is the minimum flow the peak flow of one event should have to be considered suitable;
- drainage.area: the total area draining (in square miles) to the streamflow station;
- filter: filter of the base flow separation function to be used in order to calculate the total runoff;
- plot.graphs: logical: TRUE if hydrographs should be generated;
- write.events: logical: TRUE if events should be written into csv file;
- salving.folder: the folder to save the graphs or the csv file. Default is the working folder.

REFERENCES

APPENDIX D – MAPS

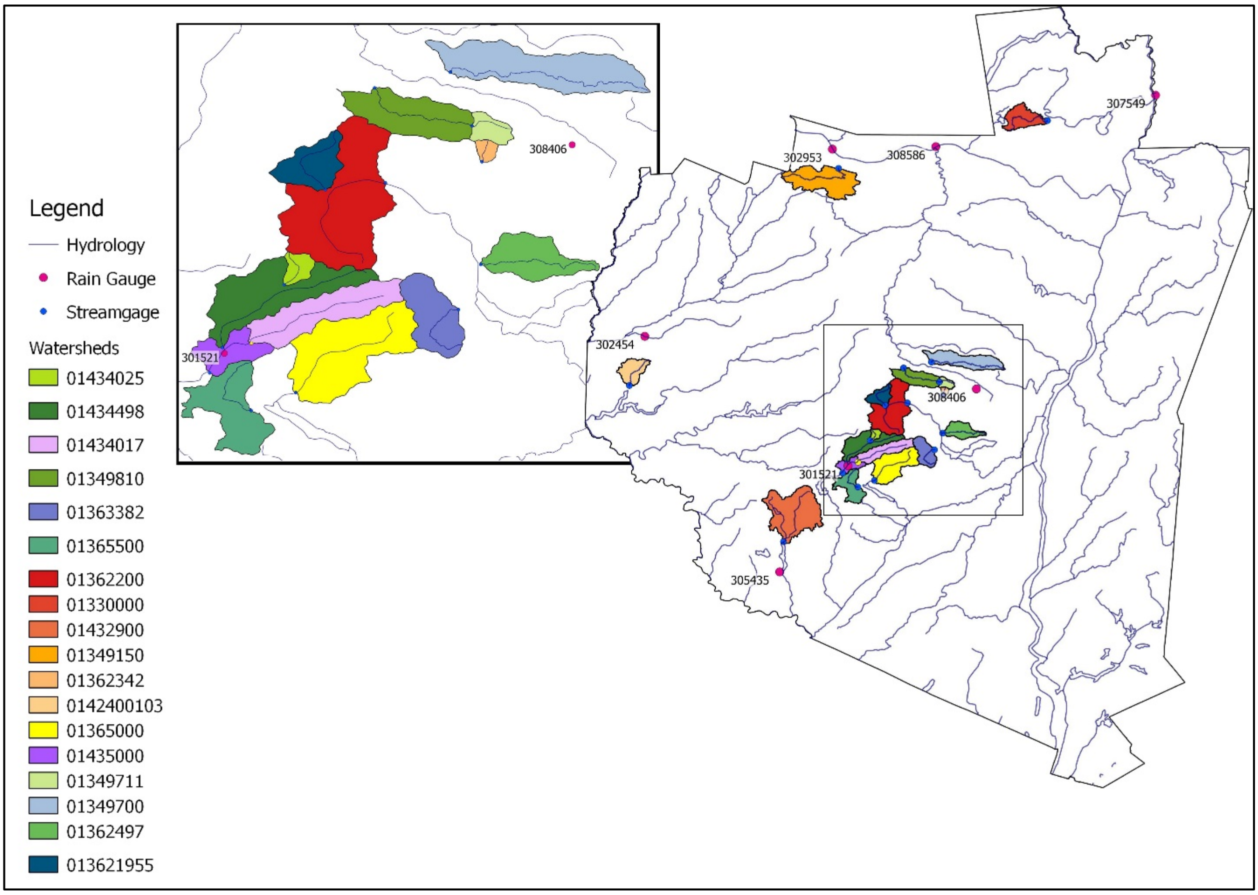


Figure 1: Streamgage stations, watershed boundaries rain gauge used in the study

Note: Station 307549 is not used, although was put on the map to illustrate the point discussed in the text; map on left is a zoom in on the square in map.

Information Transfer Program Introduction

The Director and staff of the NYS Water Resources Institute undertake public service, outreach, education and communication activities. Most are conducted through multidisciplinary projects funded outside the Water Resources Research Act (WRRA) context. In order to couple WRRA activities to other NYS WRI activities, a portion of WRRA resources are devoted to information transfer through a partnership program with the Hudson River Estuary Program, dissemination of information related to emerging issues, and student training.

Hudson River Estuary Program Partnership

Funded by the NYS Department of Environmental Conservation (DEC), the program is guided by 12 goals as part of its Action Plan formed in 1996. These goals address signature fisheries, river and shoreline habitats, plants and animals, streams and tributaries in the entire watershed, landscape and scenery, public access, education, waterfront revitalization, water quality, and partnerships and progress. WRI and DEC work together to protect this rich estuary ecosystem that is a source of municipal drinking water, spawning grounds for migratory fish, habitat for bald eagles, and an excellent recreation area for boaters, anglers and swimmers.

A summary of selected WRI information transfer activities is provided below:

New York State Water Resources Institute FY2014 Activity
For additional information on all activity, see wri.cals.cornell.edu

Peer Reviewed Publications (details provided in the Research Program section)

Conference Presentations & Invited Talks
1. Rahm, B.G. 2014. The Role of Built Environment in Economics and Public Policy (invited panelist). Modernization of New York's Built Environment Laws: If Not Now, When? Albany, NY. NOV 12, 2014

2. Meyer, A. 2014. Prioritizing Culverts and Dams in the Hudson River Estuary Watershed. InterACT Meeting. Albany, NY. NOV 7, 2014

3. Rahm, B.G. 2014. Issues and Trends in Wastewater Management in the Hudson River Watershed and NY State. Hudson River Watershed Alliance Annual Watershed Conference. Hyde Park, NY. OCT 7, 2014

4. Vedachalam, S.; Aniket, K.; Geddes, R.R.; Riha, S.J. 2014. How Small is Too Small? Scale Economies in Water Utilities. 2014 Mid-Atlantic Regional Water Conference. Shepherdstown, WV. SEP 25, 2014

5. Rahm, B.G; Riha, S.J. 2014. Gas Extraction Violations in Pennsylvania – What Can Compliance Tell Us About Water Resource Risk. 2014 Mid-Atlantic Regional Water Conference. Shepherdstown, WV. SEP 25, 2014

6. Rahm B.G. 2014. Infrastructure Challenges in the Mid-Atlantic Region (panelist). 2014 Mid-Atlantic Regional Water Conference. Shepherdstown, WV. SEP 24, 2014

7. Rahm, B.G.; Vedachalam, S.; Vail, E.E. 2014. Panel on Assessment of Water Resources Infrastructure. Community Development Institute. Ellenville, NY. SEP 18, 2014

8. Rahm B.G. 2014. Linking Water Resources Infrastructure and Community Development (panelist). Community Development Institute. Ellenville, NY. SEP 17, 2014

9. Vedachalam, S.; Riha, S.J. 2014. State of Play with Water Systems in New York State (invited). Reception hosted by Cornell Program in Infrastructure Policy. Cornell University, NY. MAR 24, 2014

10. Vedachalam, S.; John, M.E.; Riha, S.J. 2014. Spatial Analysis of Boil Water Advisories Issued During an Extreme Weather Event in the Mohawk-Hudson Watershed. Mohawk Watershed Symposium. Schenectady, NY. MAR 21, 2014

11. Blair, B.; Vail, E.E. 2014. Green Infrastructure in Rockland County (With a Focus on Sparkill Watershed). Rockland County Water Quality Committee Meeting. Pomona, NY. MAR 18, 2014

12. Rahm, B.G.; Vedachalam, S.; Tonitto, C. Riha, S.J. 2014. Tapping Higher Education for Innovation in Water Infrastructure Assessment and Planning. Hudson River Estuary Management Advisory Council. Staatsburg, NY. MAR 6, 2014

Press

1. Sanitation scores in India have room for improvement, Cornell Chronicle, February 10th, 2015.

2. Marist College features WRI researcher on winning EPA award, Marist and Cornell Chronicle, December 9th, 2014.

3. Election 2014 Recap: Voters Mostly Say ‘Yes’ to Water Spending, Circle of Blue, November 5th, 2014.

4. Why surging water consumption could end the shale gale, Alberta Oil, March 11th, 2014.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	0	0	0	2
Masters	3	0	0	0	3
Ph.D.	1	1	0	0	2
Post-Doc.	0	0	0	0	0
Total	6	1	0	0	7

Notable Awards and Achievements

Our study, “Evolving shale gas management: water resource risks, impacts, and lessons learned,” was covered by Science for Environment Policy: European Commission DG Environment News Alert Service, edited by SCU, The University of the West of England, Bristol. 4 September 2014, Issue 384, in an article entitled, “Shale gas: independent planning is key to reducing environmental impacts of fracking.”

NY WRI acted as conference co-planner: 2014 Mid-Atlantic Regional Water Conference, held in Sheperdstown, WV

WRI staff member Chris Bowser was named an EPA Region 2 "Environmental Quality Awards" recipient - see: http://yosemite.epa.gov/opa/admpress.nsf/0/32715C9EDFD4EC9285257CC300514284

Publications from Prior Years

1. 2011NY161B ("NITROGEN (N) AVAILABILITY AS DRIVER OF METHYLMERCURY PRODUCTION IN FORESTED SOILS AND STREAM SEDIMENTS ") - Articles in Refereed Scientific Journals - Vidon, P., W. Carleton, M. Mitchell, 2014, Spatial and temporal variability in stream dissolved organic carbon quantity and quality in an Adirondack forested catchment, Applied Geochemistry, 46, 10-18.
2. 2011NY161B ("NITROGEN (N) AVAILABILITY AS DRIVER OF METHYLMERCURY PRODUCTION IN FORESTED SOILS AND STREAM SEDIMENTS ") - Articles in Refereed Scientific Journals - Vidon, P., W. Carleton, M. Mitchell, 2014, Mercury proxies and mercury dynamics in a forested watershed of the US Northeast. Environmental Monitoring and Assessment, 186(11), 7475-7488.